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A TEXTBOOK

OF

EXPERIMENTAL PHYSIOLOGY

FOR STUDENTS OF MEDICINE

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TORONTO
THE MACMILLAN COMPANY OF CANADA
1909

PT
H53
123993

Printed in Great Britain

PREFACE

For some time past London teachers have felt that the Courses in Practical Physiology were unsatisfactory, in that sufficient regard was not given to the future requirements of the student of medicine. The magnification of the office of examinations, which is the bane of higher education in this country, tends to the stereotyping of teaching, and makes it difficult to design courses with the natural object of improving the knowledge of the student. And yet if a man is to understand the problems of disease, he must first be acquainted with the workings of the healthy body. It is not sufficient, nor is it necessary, that he should know all that has been written on the subject. Rather must he aim at having such a mental image of the organs of the animal body, that the latter becomes to him, so to speak, transparent, and he is able mentally to picture the disorders of function, which he infers from the signs and symptoms utilised by the medical man for the purposes of diagnosis. This knowledge cannot be obtained simply from the reading of books. Although this country was one of the earliest to require practical work in Physiology from its medical students, the ease with which the fundamental principles of physiology can be studied on the reactions of the muscles and nerves of the frog, has led to the comparative neglect of many important functions in which we need the guidance of experiments on ourselves, or on other mammals. Even at the present time, legal restrictions prevent the student from learning on the lower animals the routine of the administration of anæsthetics, or the technique of the simple operative

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procedures necessary for the investigation of the functions of the healthy body, so that his first experience in the administration of anæsthetics, as well as in surgical operations, has to be gained on man himself. It is all the more important, therefore, that those functions of the body which can only be studied in the living mammal, should be shown to the student by way of demonstration.

In the revised regulations of the University of London, a syllabus of Practical Physiology has been prescribed, which is more in accordance with the actual requirements of the student of medicine. The present work is an attempt to put this syllabus into practice. I have carefully gone through all the exercises with the authors, and I believe not only that the work contains the practical training required by the University of London of its candidates, but also that the student who has conscientiously worked through the exercises, will find that the knowledge gained thereby will materially assist him in his future work, *i.e.* in the comprehension and treatment of disease. This, at any rate, is the idea which has inspired the writers of the book.

In the first edition of a book of this character, it is impossible to avoid faults both of omission and commission, which can only be brought to light when the book is actually used in practical classwork.

The writers will therefore gladly welcome any suggestions from their colleagues in the University and its schools, as to points in which future editions of the work can be made more useful to students.

ERNEST H. STARLING.

September 1909.

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PART I

PHYSIOLOGICAL ANATOMY OF THE RABBIT

The dissection is to be made from a physiological, rather than from an anatomical standpoint. It is best carried out on an animal that has recently been killed by an overdose of chloroform.

Contents of Abdomen.—Open the abdomen by means of a median incision through the skin and muscles, beginning at the xiphisternum, and continuing towards the pelvis.

The cavity is lined with a glistening moist layer of peritoneum, which is reflected over the viscera. A finger touching the inner face of the abdominal muscles touches peritoneum; when placed on the viscera, it touches a layer of peritoneum covering these. The finger is therefore in the peritoneal cavity, and is not touching the actual surface either of the muscles or viscera.

Notice the various portions of the alimentary canal: œsophagus passing through the muscular diaphragm—stomach and pylorus—U-shaped duodenal loop—small intestine—large sacculated dark-coloured cæcum and non-sacculated thick-walled appendix—large intestine.

Note the diffuse pancreas, which appears something like isolated masses of fat, lying in the mesentery of the duodenal loop. The duct of the gland opens into the distal portion of the duodenum, about three inches below the bend of the loop.

The liver divided into lobes, with the gall-bladder on its under-side, lies just beneath the diaphragm. Trace the bile-duct to its entrance into the duodenum, about a third of an inch from the pylorus.

Note the portal vein carrying blood from the intestine to the liver, and the hepatic vein taking blood from the liver to the inferior (or posterior) vena cava, and thus to the right auricle of the heart.

Remove the intestines, cutting through the mesentery containing blood-vessels (arteries) which supply these, and veins (mesenteric) which form the roots of the portal vein.

Open the intestine throughout its length with scissors. Note that the contents become more solid as these pass towards the rectum.

Examine the ileo-colic valve between the end of small intestine (ileum) and large intestine (cæcum). The junction of the smaller with the larger tube forms almost a right angle.

Notice the Peyer's patches on the wall of the small intestine. These are masses of lymphoid tissue, which occur as thickened areas on the inner mucous surface of the ileum. They occur opposite to the attachment of the mesentery.

The large abdominal vessels, kidneys and suprarenal (adrenal) bodies, lie behind the peritoneum.

Notice the different positions of the two kidneys. Remove the fibrous capsule of one kidney. Observe the single malpighian pyramid projecting into the pelvis of the kidney. The ureter arises from the pelvis.

The adrenal bodies lie on the renal veins.

Contents of the Thorax.—Make a small aperture in the diaphragm on one side, and observe the complete collapse of the lung on that side, due to the elasticity of the lung substance itself. Now open the thorax by cutting through the ribs and removing a piece of the wall. Observe the lungs. Expose the trachea in the neck, and inflate the lungs by means of a blow-pipe.

Note the position and appearance of the heart, contained in the pericardium. Remove this membrane and note the different appearance of auricles and ventricles, and the connection of the chief blood-vessels with the heart :—

(1) The Aorta	from left ventricle.
(2) The Pulmonary Artery .	,, right ,,
(3) The two Superior Venæ Cavæ	,, right auricle.
(4) The Inferior Vena Cava .	
(5) The Pulmonary Veins .	,, left ,,

Remove the heart. By means of a pipette in the inferior vena cava, pass water through the heart. Try this with the pipette in the aorta. The water does not pass. This is due to the arrangement of the valves of the heart.

Open the cavities of the heart and examine the valves.

(1) Left auriculo-ventricular valve—mitral.
(2) Right auriculo-ventricular valve—tricuspid.
(3) Semilunar valves at the orifices of aorta and pulmonary artery respectively.

Nerves of the Neck.—Place the carcase on its back, cut off the hair from the front of the neck, and moisten the skin to prevent the hairs flying about. Make a median incision through the skin of the neck, about 3 inches long. Separate sternomastoid from sternohyoid muscles. The carotid sheath is thus exposed, the *descendens noni* nerve, a branch of the hypoglossal, lying superficial to it. Lift up the carotid, and see *three* nerves running with it, somewhat deeper. The largest, white, nerve is the *vagus*. The next in size, grey, is the *sympathetic*. The smallest nerve is the *depressor*. Put a ligature round each nerve, and examine the connections of the depressor nerve above.

In all these operations proceed as if you were doing an actual experiment. *Do not make a dissection of the neck.*

Accelerator Nerves.—Prolong the skin incision to the sternum. Cut away the insertion of sternomastoid, and holding the cervical sympathetic by its ligature, trace it downwards. At the lower part of the neck it thickens to form the inferior cervical ganglion. This gives off a small branch, which courses with the depressor nerve towards the heart. Below, the inferior cervical ganglion is connected by two strands, which pass in front of and behind the subclavian artery, to the stellate ganglion. These strands are the Annulus of Vieussens. To trace out the connections of the stellate ganglion, it is often helpful to remove (after applying double ligatures) the subclavian artery and vein, and also the greater portion of the first rib.

The *stellate ganglion* receives fibres by the white rami of the upper three or four dorsal nerves, and gives off cardiac branches (accelerator), vertebral nerve, and the Annulus of Vieussens.

Splanchnic Nerve.—This is best dissected from behind, but is easier to do from the front. Put the rabbit in the prone position, and make an incision, half an inch below and parallel to the last rib, down to the muscle. Retract the erector spinæ, and incise the lumbar fascia close to the spine. Put in the fingers, enlarge the opening, and look for the suprarenal body. Pull this outwards, and the splanchnic may be seen running outwards and downwards, as it emerges from the crus of diaphragm.

If the dissection fails, turn the rabbit over, and dissect the splanchnic from the front.

Nervi Erigentes (pelvic nerves).—Make a median incision in the lower part of the linea alba, to the bottom of the symphysis. Cut through the symphysis, and force the two sides of the pelvis apart. Retract the peritoneum. The pelvic nerves will be seen running with the vessels, from the upper part of the sacrum to the side of the rectum. Put a ligature loosely round the nerve.

PART II—SPECIAL EXERCISES

MUSCLE

LESSON I

BATTERIES—COILS—KEYS—EXCITABILITY OF MUSCLE AND NERVE

Batteries.—*Observations.*—It is customary to use some form of cell to produce the electric current required for physiological purposes. Four varieties of cell are in common use:—

1. *The Leclanché Cell.*—This consists of a glass jar, containing a solution of sal-ammoniac. Into this di [illegible] amalgamated rod of zinc, which is the positive plate. A [illegible]ce of gas carbon forms the negative plate. This is surrounded by peroxide of manganese (MnO_2), which is kept in contact with the surface of the carbon by being placed in a porous pot. In some forms of Leclanché the manganese and carbon are ground up together, and pressed into a cylinder which surrounds the zinc rod.

When the cell is on open circuit—that is, when the terminals are not connected, and no current is passing—very little action takes place; but when the circuit is closed, and the current passes, the zinc dissolves in the sal-ammoniac, forming a double chloride of zinc and ammonia, while ammonia gas and hydrogen are liberated at the carbon pole. The nascent hydrogen reduces the peroxide of manganese, and so polarisation is prevented. On account of its great solubility in water the ammonia has no polarising action.

The Leclanché is a convenient form of cell, as when once set up it requires a minimum of attention. If it is worked through a considerable resistance it will keep in order for some time, particularly if the work is intermittent; but if it is used with a small resistance in circuit it polarises very rapidly. The E.M.F. of one Leclanché cell is 1·4 volts in the external circuit. The positive current is conventionally said to run from the zinc to the carbon in the cell, and from the carbon to the zinc in the circuit outside. The wire attached to the carbon is the *positive pole*, that to the zinc the *negative pole*.

2. *Dry cells* are usually Leclanché cells, in which the solution of sal-ammoniac is prevented from spilling by absorption with sawdust or plaster of Paris. The E.M.F. is the same as the Leclanché, but they polarise much more readily.

3. *Daniell's Cell.*—This consists of a vessel of copper, containing a saturated solution of copper sulphate. In this is placed a porous pot, which contains dilute sulphuric acid (1 in 10), or a solution of zinc sulphate, and into this dips a rod of amalgamated zinc. When the zinc and copper are connected by a wire, the positive current flows along this from the copper to the zinc, the latter metal dissolving in the sulphuric acid, and metallic copper being deposited on the copper vessel. The solution of the zinc takes place according to the equation

$$Zn + H_2SO_4 = ZnSO_4 + H_2$$

and the hydrogen got rid of by the deposition of the copper, according to the equation

$$H_2 + CuSO_4 = H_2SO_4 + Cu$$

so that the complete changes taking place during activity can be represented as

$$Zn + CuSO_4 = ZnSO_4 + Cu$$

The positive current flows from the zinc to the copper inside the cell, from the copper to the zinc outside the cell. The end of the wire connected with the zinc is therefore the negative pole of the battery, that connected with the copper the positive pole. The E.M.F. of the cell made up as just stated is 1·178 volts.

These cells polarise much less readily than a Leclanché, and consequently are a much more constant source of E.M.F., but they are more troublesome to keep in order.

4. *Accumulators.* The ordinary form of accumulator consists of a vessel containing dilute sulphuric acid, into which dip two lead plates. In the discharged condition both plates

are acted on by the acid, and are largely converted into $PbSO_4$. When an electric current is sent through the cell, the plate by which the current enters, the *anode*, becomes oxidised to PbO_2, according to the equation

$$PbSO_4 + 2H_2O + SO_4 = PbO_2 + 4H + 2SO_4$$

The plate by which the current leaves the cell, the *kathode*, becomes reduced to metallic lead—

$$PbSO_4 + H_2 = Pb + 2H + SO_4$$

In this state the accumulator is said to be 'charged.'

As the equations just given are reversible, it follows that, when the plates are connected together, the accumulator acts as a battery. The plate coated with Pb now becomes the anode, that coated with PbO_2 the kathode, and the positive current flows outside the cell from Pb to PbO_2, until both plates are again changed to $PbSO_4$.

The E.M.F. of an accumulator is 2·0 volts during the greater part of its discharge. The internal resistance is low, and a well-made accumulator can yield a very heavy current; but all accumulators require constant attention, and, as a rule, accidental short-circuiting buckles the plates, and renders the cell useless. The student must therefore take particular care not to connect the two terminals of an accumulator, unless there is sufficient resistance in the circuit to avoid this accident.

Induction Coils.—It is often necessary for physiological purposes to use an electric current of a high potential, and apply this at a given moment of time. Both these ends can be attained by the use of an induction coil. The form in universal use is the modification of Ruhmkorff's, devised by Du Bois Reymond. This consists of a primary coil, composed of comparatively few turns of thick wire, and a secondary coil of many turns of fine wire. A current of low E.M.F., taken from one of the cells just described, is sent through the primary coil; while this current is flowing steadily, no effect is produced in the secondary coil, but at the moment of make, and again at the moment of break, a current is *induced* in the secondary, the current at make being in the reverse direction to that of the primary, and the current at break being in the same direction.

With a given coil the E.M.F. of the induced current depends on three factors:

(1) The strength of the magnetic field produced by the primary. This can be varied (*a*) by altering the E.M.F. of the primary current, (*b*) by concentrating the lines of force by a core of soft iron wires.

(2) The number of lines of force cut by the secondary. This will depend on (*a*) the number of turns of wire in the secondary, (*b*) its position. If the secondary is moved away from the primary, or inclined at an angle to it, fewer lines are cut, and the E.M.F. is diminished. The current in the secondary coil varies approximately as the square of the distance from the primary, and the cosine of the angle of inclination to it.

(3) The rate at which the lines of force are cut. The only variant that need be considered is the rate of change in strength of the primary current. If this changes slowly, the E.M.F. of the secondary will be less than if it changes rapidly.

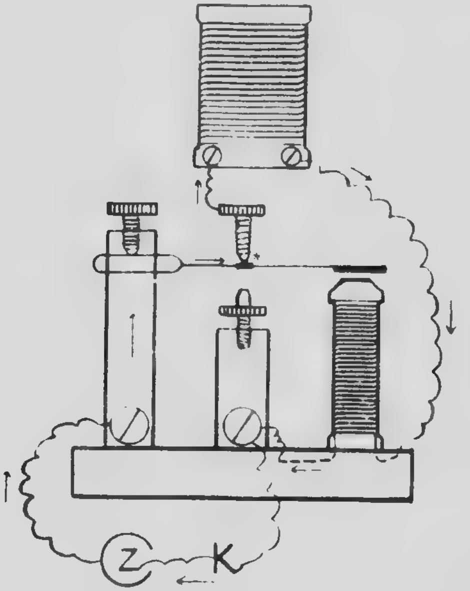

Fig. 1. Neef's hammer. The current is made and broken at the point marked *.

It is often necessary to use a rapid series of induction shocks, and for this purpose the primary circuit is made and broken by an automatic device, known as Neef's hammer.

The battery current, on its way to the primary coil, passes through a spring, and a screw which is in contact with its upper surface. After traversing the primary coil, the current excites a small electro-magnet, the poles of which lie just below a soft iron armature, attached to the free end of the spring. When the battery current passes, it excites the electro-magnet, and draws down the armature, thus moving the spring out of contact with the screw, and thus breaking the primary circuit at this point. The battery current therefore ceases, and the electro-magnet is no longer excited, the spring flies back by its own elasticity, and once more makes contact with the screw, the battery current again passes and excites the magnet as before. Contact is thus made and broken at a rate determined by the vibration period of the spring.

In order to diminish the difference of intensity of the induced current at make and break, the device invented by Helmholtz and called the 'Side Wire' may be used. This consists of a wire so placed as to connect the battery with the primary coil, when the spring is out of contact with the screw, which is moved up out of reach of the spring altogether. Another screw, situated below the spring, is elevated until it makes contact with the spring when the armature is attracted to the magnet. This contact is arranged in a short circuit, which cuts out both primary coil and electro-magnet. The magnet becomes so weak that the armature flies back, breaks the short circuit, and the current now once more passes through the long circuit *via* the primary coil and magnet. With this arrangement the primary circuit is never broken, only short-circuited, so that some current always passes through it, this current being weakened and strengthened by the making and breaking of contact by the Neef's hammer.

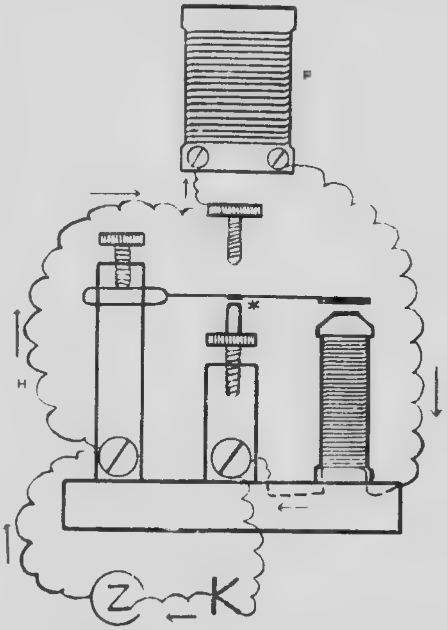

Fig. 2. Helmholtz side wire (H). The current is short-circuited at the point marked *.

Both make and break extra currents are thus produced in the primary coil, and the make and break induced currents in the secondary coil are therefore both proportionately weaker.

Keys.—The key is a device for making or breaking an electric current. Three patterns only need to be described: (1) Du Bois Reymond's; (2) The Mercury key; (3) The Spring key.

(1) *Du Bois Reymond's Key.*—On an insulating base are placed two binding screws with smooth brass faces. Attached to a vulcanite handle is a third piece of brass, which is mounted on a hinge, and arranged so that when it is depressed it forms a metallic bridge between the two binding screws, so completing the circuit.

(2) *The Mercury Key.*—This differs only in detail from the preceding. One binding screw is attached to the brass or copper key, the other is connected with a little mercury pool; when the key is depressed it dips into the pool and completes the circuit.

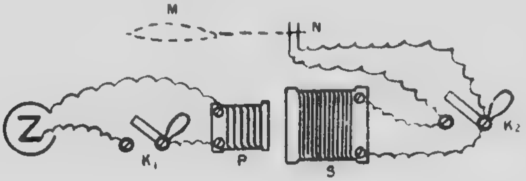

Fig. 3. The key K_1 is used to open and close the circuit through the primary coil, P. The key K_2 short-circuits the current from the secondary coil, S.

(3) *The Spring Key.*—In this form the brass connecting piece is made to form a flat spring. When depressed by the finger this makes contact with two platinum points (preferably with two platinum cross wires). When released the spring breaks the circuit.

All these keys can be used in one of two ways:

(*a*) Simply to make and break a circuit, as in K_1 in Fig. 3.

(*b*) As a short-circuiting key, K_2 in Fig. 3. This use of the key depends on the law, that when a circuit is divided the amount of current in the two portions is inversely proportional to their resistance. In most physiological experiments the resistance in the electrode circuit (N in Fig. 3) is to be measured in tens of thousands of ohms, while the resistance of the key itself is less than an ohm. The fraction of current passing through N will therefore be so small that it can be neglected.

Commutators.—These instruments are used for two different purposes:

(*a*) Altering the direction of a current;
(*b*) Sending a current through one of two circuits: for example, either through a nerve or muscle.

(*a*) The simplest form of apparatus for altering the direction of a current is the circular commutator of Waller (Fig. 4). This consists of two semicircular pieces of brass, with a transverse piece of ebonite crossing them. The ends of the ebonite have two metal contacts, which connect with the brass strip below, and with the binding screws on the top of the ebonite above. When the ebonite strip is rotated the contacts with the strips below are reversed, and the current of the upper screws is changed in direction. Gotch's modification of this has an intermediate piece of brass between the inside pieces, but otherwise is constructed on the same principle. In using either form of commutator the student must see that the contacts are clean and bright.

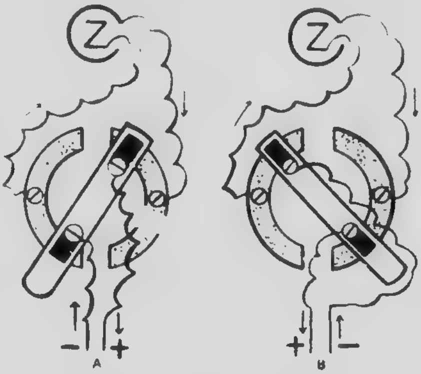

FIG. 4.—Waller's commutator.

(*b*) To send a current into one of two circuits either a double key can be used (Fig. 5) or two single keys arranged on a switchboard (Fig. 6). The latter is the better method, as the circuit not in use is guarded by the second short-circuit key.

Pohl's commutator can be used for either purpose. It consists of an ebonite base with six mercury pools. A rocking arm dips into the two centre pools, and connects these with one or other of the end pair of pools, so reproducing the arrangement in the double key (Fig. 5).

To alter the direction of a circuit with the Pohl commutator two cross wires are used, insulated from each other, which connect the two corner pools diagonally across the base (E with D, C with F). The battery is connected to the centre pools (A and B) as before, and the preparation (N) with one pair of the end pools; the direction of the circuit is altered when the rocking arm is moved across.

Figs. 7 and 8 represent the commutator in its two positions.

Experiments.—Set up the circuit as shown in Fig. 3, and verify the above statements, placing the electrodes N on the tongue. The student will find—keeping the key K_2 open—

(1) That in making or breaking the primary circuit at K_1, the 'make' shock is weaker than the 'break';

(2) That both shocks become stronger as the secondary coil S approaches the primary, P.

When the key K_2 is closed the secondary circuit is short-circuited, and neither make nor break shocks will be felt.

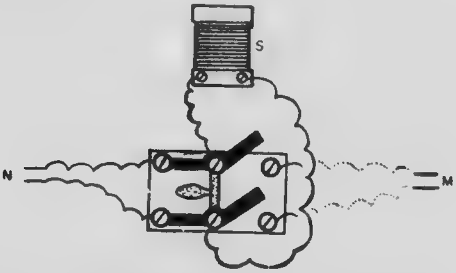

FIG. 5.—Double key. The current passes either to N, as shown, or to M, where the key is reversed.

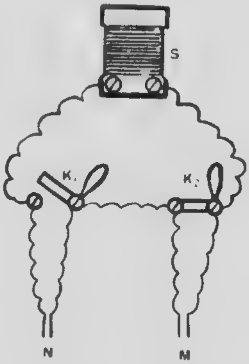

FIG. 6.—Two single keys arranged as a switchboard. Current passes to N, and M is short-circuited. On opening K_2, and closing K_1, the current passes to M.

The student will note that he must not use a key in the primary circuit to short-circuit an accumulator or Leclanché cell, as the resistance would be so small that the accumulator would be immediately discharged. He also should not use a simple opening and closing key in the secondary circuit of an induction coil, as the E.M.F. of the current is so high that, as a rule, sufficient current escape will take place to excite the tissue, even when the key is open. Set up the circuit as shown in Figs. 4 and 7. Test the terminals with pole-testing paper, and note the alteration in the direction of the current, as the commutator is reversed, or the Pohl rocker moved across.

The Gastrocnemius-Sciatic Preparation.—Take a frog which has been pithed, and make a circular incision through the skin right round the animal, a little below the ensiform cartilage. Hold the fore legs of the frog firmly, and pull down the trousers of skin thus formed. The skin will separate quite

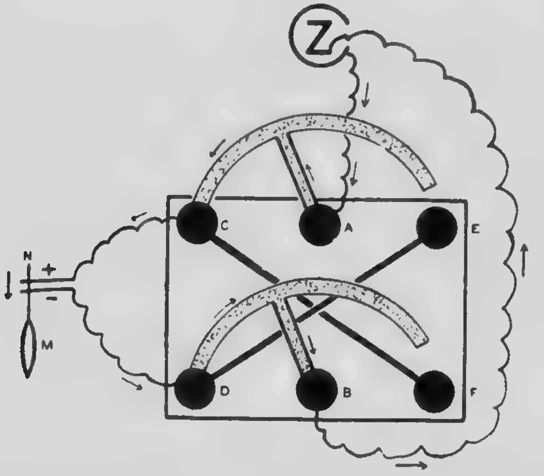

Fig. 7.—Pohl's commutator, with cross-wires in. Current is a descending one through the nerve, N.

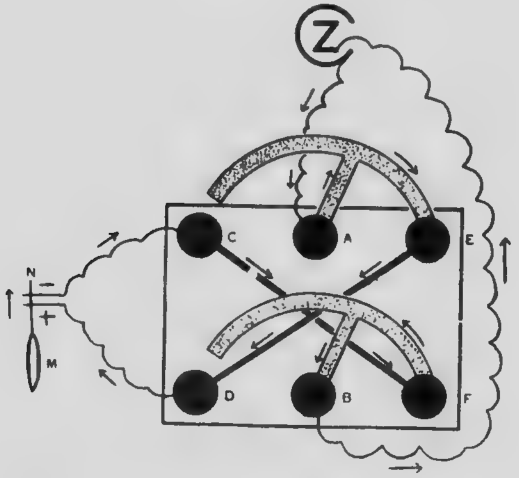

Fig. 8.—Pohl's commutator, with cross-wires in, second position. Current is reversed in direction through the nerve, N.

easily and leave all the muscles exposed. With the fingers gently separate the hamstring muscles, so as to show the sciatic nerve lying between them.

Next snip through the tendo Achillis and gently separate the gastrocnemius up to its origin from the femur. Transfix the sesamoid cartilage of the tendo Achillis with a bent pin to which a fine thread has been attached. If preferred, the thread can be tied round the tendo Achillis directly. Moisten the muscle with normal salt solution (0·6 per cent. NaCl in tap water) and proceed to dissect out the sciatic nerve.

This is most easily accomplished from the back. Gently raise up the urostyle, and free it from the muscles attached, cutting close to the bone. Cut through the urostyle close to its origin. Next pass the blade of the scissors close to the innominate bones, and cut upwards, continuing the cut so as to free the last two or three vertebræ on either side. Next pass one blade of the scissors exactly in the middle line under the vertebral column, and divide the last three vertebræ laterally; finally isolate these with a transverse cut. If the piece of bone thus isolated be gently lifted up, it will carry with it the sciatic nerve. Free this nerve from the muscles and fascia which surround it, taking particular pains not to pull the nerve, or touch it with forceps; isolate the nerve right down to the knee, lay it down on the gastrocnemius, and moisten it with salt solution.[1] Next cut through the tibia, just below the knee, free the femur from the hamstring muscles and cut it through about the middle.

As an alternative method, when the frog has been pithed, hold the legs firmly, cut through the anterior abdominal muscle, let the viscera fall forwards, and divide the spinal column above the urostyle. Pull off the skin as before. This leaves the sacrum with the lower limbs attached, which can be prepared as just stated.

The Crank Myograph.—The muscle-nerve preparation should then be placed on the crank myograph (Fig. 9). This has an axis, A, about 5 mm. in diameter, bearing a short arm, M, to which the muscle is attached by a thread, which is wound round two or three times and fastened with modelling-wax. The long arm bears a writing-point, P. A third arm, T, rests against a screw stop, S, so that the weight, W, is supported as an after-load, being raised as soon as the muscle begins to contract. The muscle, M_1, is pinned through the ligaments of the knee joint to a cork on the frog-board.

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[1] The whole of this dissection should be done with a pair of sharp scissors. Never tease out a nerve with a scalpel as in the dissecting room. The nerve must never be taken hold of with the forceps, and all dragging on the nerve or unnecessary manipulation should be avoided as far as possible.

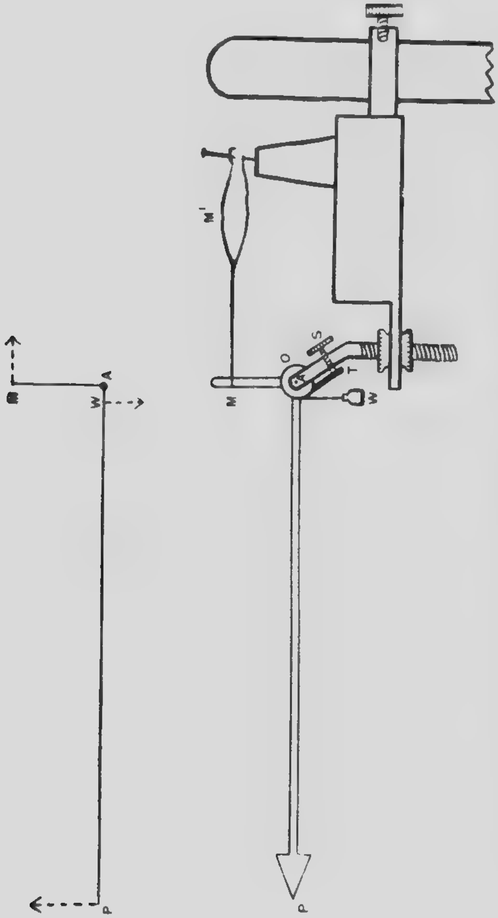

FIG. 9. Crank myograph. M', muscle; W, weight; A, centre of rotation of lever; B, axle round which the string of the weight passes; T, after-loading pin screw.

The weight is hung by a thread on to the small pin on the axle, so as to be as near the axis of revolution as possible.

Excitability of Muscle and Nerve. — (*a*) Connect the electrodes on the crank myograph with the wires from the secondary coil as in Fig. 3. Place the secondary coil at such a distance that both make and break shocks are distinctly felt on the tongue. By opening the key K_2 and closing K_1, send the induction shocks through (1) the nerve, (2) the muscle; note that the muscle contracts in both cases. A muscle can therefore be stimulated either (i) indirectly through the nerve, or (ii) directly by an exciting shock applied to itself. Record both contractions on a stationary drum.

(*b*) Open K_2 and close K_1 so as to excite the nerve. Pull out the secondary coil so that break shocks are no longer effective. Then gradually push the coil back again, and test the make and break shocks separately. With most coils it will be found

(1) That the break shock is effective at a greater distance from the primary than the make. Record each contraction on a stationary drum, marking the distance of the secondary in millimetres underneath the record of each contraction.

Notice (2) the height of the contraction. It increases gradually from a minimum to a maximum, and then remains at the latter height, even if the secondary coil is pushed right over the primary. Striated muscle can therefore, within certain limits, give a graduated response to a graduated stimulus. This is probably due to the increase in the number of fibres contracting when the shock is increased, not to an increase in the height of the contraction of each fibre.[1]

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[1] Gotch and Keith Lucas.

LESSON II

SIMPLE MUSCLE TWITCH—LATENT PERIOD—ACTION OF CURARI AND VERATRINE

Simple Muscle Twitch.—Set up another gastrocnemius-sciatic preparation on a crank myograph, as in Lesson I. Arrange the rotation of the drum so that the smoked paper passes the writing-point of the lever at the rate of 20 c.m. per second. With the ordinary size of drum, which is 50 c.m. in circumference, the whole drum will then rotate once in 2·5 seconds. Arrange the circuit from the secondary coil as before, and close the short-circuiting key. Introduce the drum into the primary circuit, so that the current only passes when the brass spring on the axle of the drum is in contact with the insulated pointed pin of brass on the stand, to which the battery wire is attached, and place the secondary coil so far from the primary that break only is effective. See that the join in the paper is at the opposite side of the drum from the writing-point, when this happens. Close K_1 and draw a base line by allowing the drum to rotate without stimulating the nerve (Fig. 10).

To record a single twitch. (1) See that the short-circuiting key is closed. (2) Close the key K_3 in the primary circuit. (3) Start the drum. (4) Open the short-circuiting key K_1. As soon as the muscle has contracted, close K_1 again and stop the drum.

To complete the record it is necessary to time the tracing by means of a chronograph. The simplest form is a large tuning-fork, with a vibration period of 100 per sec., mounted in a convenient handle, and provided with a writing-point on one of its prongs. It is put into vibration by striking it, and the vibrating point is then placed against the revolving drum immediately below the tracing of the twitch; the undulations thus traced represent each $\frac{1}{100}$th sec. A more accurate method is to employ an electrically operated tuning-fork, connected with an electro-magnetic signal which vibrates synchronously with the fork. This can be conveniently arranged to record the time tracing simultaneously with the muscle twitch.

Latent Period.—To ascertain the latent period, *i.e.* the time that has elapsed between the stimulation of the nerve and the first visible contraction, it is necessary to mark the time at which the induction shock is applied to the nerve. Close K_2, open K_1, and bring the drum round slowly by hand until it just breaks contact; the muscle will again contract, and write a straight line on the nearly stationary drum.

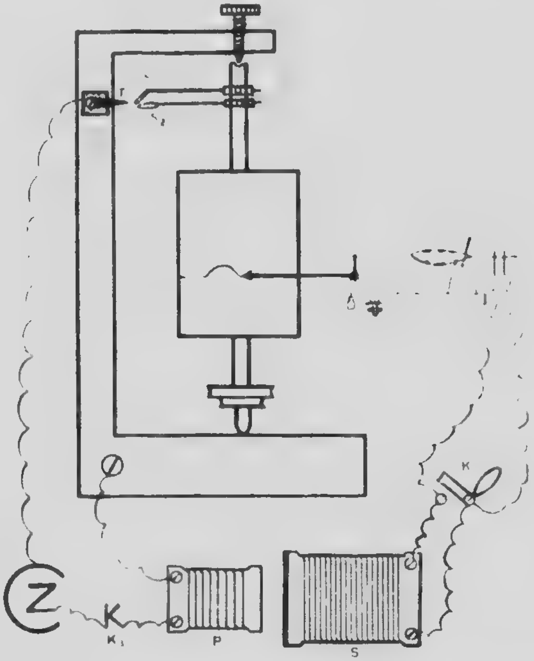

FIG. 10. Circuit for one or two twitches. The springs s_1 and s_2 just touch the trigger T when the drum revolves, so momentarily making the circuit through the primary coil P.

Under the conditions of experiment the latent period will be about 0·01 sec. This is compounded of at least three separate factors, which are approximately as follows:—

	Second.
(1) The time taken to traverse 3 cms. of nerve	0·001
(2) True muscle latency	0·0035
(3) Stretching uncontracted part of fibre and overcoming inertia of apparatus	0·0055
	0·0100

Study the whole curve, and measure the length of the period of contraction, and the period of relaxation. If the preparation has been skilfully put up, these will occupy approximately the same time—about 0·06 second. Measure the height of the curve; this will give the true shortening of the muscle when multiplied by the factor $\frac{c}{L}$, where c equals length of the short arm of the crank, measured from the point where the thread is attached, to the centre of the axle, and L equals the length from the centre of axle to the writing-point. Measure both these lengths and calculate the true height.

If the weight which the muscle has lifted has been suspended round the axle, as recommended in Lesson I., the tension on the muscle will have been nearly constant throughout the contraction; hence this way of recording the muscle twitch is called the *isotonic* method.

If a muscle is prevented from shortening and the changes in tension recorded, an *isometric* curve is obtained.

Action of Curari.—Use a hyoglossus-hypoglossal preparation obtained as follows:—

Remove the skin from the throat, and remove the sternum, snipping through the shoulder girdle on each side, and severing the sternum from the hyoid bone. The hypoglossal nerve will be seen at the level of the fore limb, passing inwards towards the middle line, and then upwards to supply the tongue muscles. Tie a thread to it, close to the ansa. Divide it, and dissect it out as far as the hyoglossus muscle. Divide the ramus of the lower jaw on each side, when it will come away, carrying the hyoid bone and tongue. Tie a thread round the tip of the tongue, and attach it to the crank myograph in the usual way. Pin the hyoid bone down to the frog-board, place the hypoglossal nerve across the electrodes, and stimulate in the usual way: the muscle contracts.

(1) Apply a 1-in-1000 solution of curari in normal saline, snipping through the mucous membrane to allow it to reach the muscle, or inject the drug by means of a small hypodermic syringe. Leave for half an hour. Stimulate the nerve a second time as before; no contraction will result. Apply the electrodes directly to the hyoglossus muscle itself and stimulate; the muscle contracts vigorously.

(2) Make a second experiment, applying the drug to the hypoglossal nerve only. In this case the muscle continues to respond to excitation of the nerve.

Experiment (1) shows that the muscle [illegible] not affected by curari, as it still responds to direct excitation; (2) shows that the nerve trunk is not affected by the strength of solution used: it must therefore be the neuro-muscular junction that the drug selects for its special action.

Action of Veratrine.—Make a third experiment, injecting a few drops of a ·002 per cent. solution of veratrine acetate in normal saline. After allowing time for the drug to act, take a series of single twitches on a slow drum. Note the difference between the first twitch, and those occurring later. Wait for five minutes and take a second series.

LESSON III

EFFECT OF LOAD—WORK DONE—FATIGUE—THE DYNAMOGRAPH—RIGOR—ACIDITY OF FATIGUED MUSCLE

Effect of Load.—A load may be applied to a muscle in two ways. It may be allowed to stretch the uncontracted muscle, or so arranged that the load is not borne by the muscle until it begins to contract. The latter method is known as 'after-loading.'

Arrange a gastrocnemius-sciatic preparation with a crank myograph as before, after-loading the muscle.

Calculate the magnification of the lever, and the actual weight lifted by the muscle, as in Lesson II. Now take a series of single twitches on a stationary drum, exciting with a single maximal break induction shock, and increasing the actual weight that the muscle lifts by increments of forty grammes. The heights of the successive contractions will diminish as the weight increases. The work done will not follow the same law. This (in gramme millimetres) is given by the height of the contraction in millimetres multiplied by the weight lifted in grammes. As the load increases, the work done increases up to a maximum, and then declines. Plot out the relation between load and work on squared paper.

The student will note that neither the power of a muscle, *i.e.* the work done in a unit of time, nor the efficiency, *i.e.* the ratio between the effective work done and the energy consumed, is given by this calculation.

The absolute force of a muscle, *i.e.* the maximum weight which a muscle can lift irrespective of height, is, for a muscle with parallel fibres, proportional to the transverse sectional area. For frogs' muscle it is about 3,000 grammes per sq. cm.; for mammalian, from 8,000 to 10,000 grammes. As the fibres of the gastrocnemius are not parallel, the calculation becomes too complex to be inserted in this pla

Fatigue.—The effect of fatigue on muscle can be studied either as it affects the shape of the curve of a single twitch, or the height of a contraction.

For the first method arrange the drum so that the striker makes a single contact at each revolution, which should occupy 2·5 seconds. See that the writing-point is a fine one. Start the drum, and then open the short-circuiting key, so that one stimulus will reach the muscle at each revolution. Allow the drum to rotate for some time, so as to obtain a large number of twitches, which will be superposed on each other. Mark the moment of excitation as before. Instead of recording every contraction, the lever may be moved so as to write on the drum only at every twentieth contraction. In this way it is possible to follow out the changes in the shape of the individual contractions resulting on fatigue.

The Dynamograph.—The progress of fatigue in the human subject can be demonstrated by the use of Mosso's ergograph, or more accurately by Waller's dynamograph. This consists of a strong spring, to which is attached a long and light lever arranged to write on a very slowly moving drum. Two handles are arranged so that the grasp of the whole hand bends the spring. The subject makes a series of maximal grasps at accurately regular intervals, as determined by the metronome, and should not look at the record until it is finished.

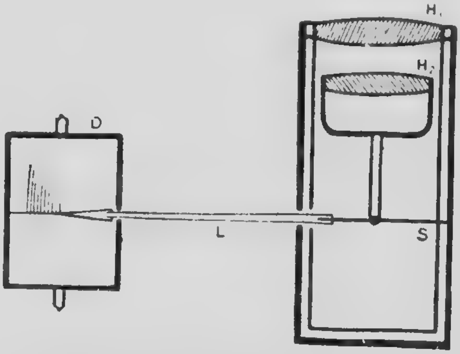

FIG. 11.—Waller's dynamograph. The movable handle H_2 is pulled up by the grasp of the hand against the stiff spring S.

Changes in Reaction of Fatigued Muscle.—Take the reaction, with moistened litmus paper, of (*a*) fresh frog's muscle, (*b*) muscle that has just been fatigued. The fresh muscle will be alkaline, the fatigued muscle acid.

Rigor.—A variable time after the death of the frog, the muscles also die. The visible sign of this occurrence is that they become shorter, more opaque, and stiff and are no longer irritable, this condition being termed *rigor mortis*. The reaction also becomes acid to litmus, as in fatigued muscle. These conditions can be well observed on muscles that have been kept since the last class.

The action of heat when above a certain temperature produces an analogous condition, which is termed 'heat rigor.' The first step in this takes place in the frog at a temperature of from 40° to 42°. Take the reaction of a fresh gastrocnemius muscle on a crank myograph, surround it with a coil of copper tubing, through which water heated to 45° is passed, and observe the contraction as the muscle passes into rigor. Then take the reaction again.

LESSON IV

EFFECTS OF HEAT AND COLD—SUMMATION—GENESIS OF TETANUS—ELECTRICAL CHANGES—GALVANOMETERS—ELECTROMETERS

Effects of Heat and Cold.—*Experiments.*—Arrange a gastrocnemius-sciatic preparation to record a single twitch as in Lesson II (Fig. 10). Place round the muscle a little spiral coil of copper tubing, as in the last lesson, and perfuse this with water from a beaker. Place a thermometer in the beaker, and take several tracings at different temperatures, *e.g.* at 7°, 15°, and 30°. Notice the alteration in (1) the latent period, (2) the rate of contraction and relaxation, and (3) the height of contraction. Finally, perfuse the coil with water at 40°, and observe the onset of heat rigor.

Summation.—Arrange the circuit and drum to record a single twitch as in Lesson II, taking a fresh gastrocnemius-sciatic preparation. Bring the second contact spring of the drum down, so that it also completes the circuit as the drum revolves, immediately after the end of the first contraction, and record with two stimuli, the second at the end of the contraction from the first. Next move the second spring backwards, so that it completes the circuit as the lever falls during the relaxation from the first stimulus. Take another record. A third is taken with the second stimulus thrown in during the first contraction; and, finally, a fourth with the second stimulus applied during the latent period of the first contraction.

The experiment may be carried out using maximal, submaximal, minimal, and subminimal stimuli. Compare the tracings obtained.

Genesis of Tetanus.—Rearrange the apparatus, so that the drum is disconnected from the primary circuit of the induction coil, and put instead the spring interrupter (Fig. 12). This is a vibrating metallic reed with a pin at one end. The contact is made and broken as the pin dips in and out of a little pool of mercury. It is well to cover the surface of the mercury with absolute alcohol to prevent oxidation. The period of vibration of the reed can be varied by sliding the clamp *c* to and fro.

Place the secondary coil at such a distance from the primary that only the break-shocks are effective. Arrange the drum so that it revolves once in about seven seconds, close the short-circuiting key in the secondary circuit, set the reed vibrating, and then open the key so as to record a series of twitches. Repeat, shortening the spring each time ; note that the individual twitches tend to become fused as the stimuli become more rapid, finally giving a sustained 'tetanus.' Note also the relation between the height of a single twitch and that of a complete tetanus, letting the muscle contract first against a light load and then against a heavy.

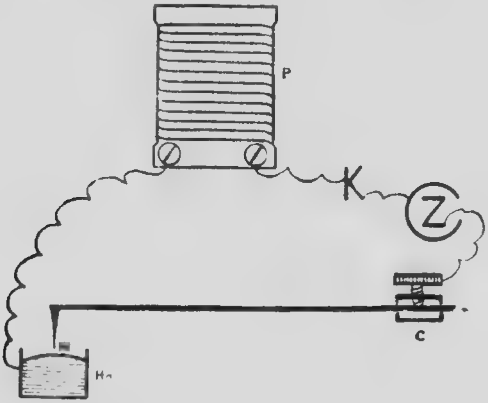

FIG. 12.—Spring interrupter. The current is made and broken at the star.

Electrical Changes in Muscle and Heart. *Observations.*—When a muscle passes from a state of rest to a state of activity differences of electrical potential are set up. Two kinds of instruments are used for observing and measuring these effects :—

(*a*) Galvanometers.
(*b*) Electrometers.

The construction and use of a galvanometer can be demonstrated on the small model. This consists of a magnetic needle, pivoted so that it rotates in a horizontal plane. It is surrounded by a vertical coil of wire, and the whole instrument is placed so that the coils of wire lie in the magnetic meridian, thus being parallel to the magnet. When a current of electricity passes through the coil, it forms a magnetic field, under the influence of which the needle tends to set itself at right angles to the plane of the coil.

The Reflecting Galvanometer of Kelvin (Thompson) is essentially the same instrument made more sensitive by careful attention to detail. The magnets are arranged in two sets, the lower set being the reverse way of the upper, so that the combination is nearly astatic. The upper set of magnets carries a small mirror, and a beam of light reflected and projected from this on a scale indicates the deflections. The coils are made of very thin wire, and are of great length, so that the resistance is high—usually about 7,000 ohms.

The Einthoven String Galvanometer has the position of the magnets and coil reversed. The magnets are large and very powerful, and the coil traversed by the current to be measured hangs in a narrow chink between the magnets. The simplest form of coil is a single straight wire, and in the Einthoven instrument this is made of a silvered quartz fibre or a platinum wire, the thickness of which is about 2·5 μ. The movement of the string is magnified by a microscope, passing through one of the poles of the magnet.

The Capillary Electrometer is constructed on a totally different system. It consists of a capillary glass tube with a bore of 10–30 μ, one end of which widens out into a reservoir; the narrow end dips into 10 per cent. sulphuric acid.

The wide end is filled with mercury under pressure. The junction of the mercury with the sulphuric acid in the capillary is the seat of surface tension, which is very easily altered by differences of potential, so that the meniscus moves up and down the tube when the potential of the connections is varied. Up to about 0·4 volts the excursions are proportional to the E.M.F., and the mercury begins to move as soon as the E.M.F. changes, so that there is no 'lost time'; it is therefore possible, by analysing the shape of the curve, to calculate the E.M.F. at any moment.

Non-Polarisable Electrodes.—In the examinations of the differences of potential shown by any animal tissue, it is essential that the contacts with the tissue shall give no current themselves. Hence non-polarisable electrodes are invariably used. These consist of a terminal of amalgamated zinc, dipping into a saturated solution of zinc sulphate contained in a small glass tube; the end of the tube applied to the tissue is closed by a plug of kaolin moistened with salt solution.

Demonstrations.—Set up the circuit as in Fig. 13. Dissect out a gastrocnemius-sciatic preparation with as little injury to the muscle as possible. Place one electrode on the belly of the muscle, the other on the tendon, contact being made through linen threads moistened with salt solution. The more carefully the preparation is made the less will be the current, and the inference is that resting uninjured tissue is iso-electric.

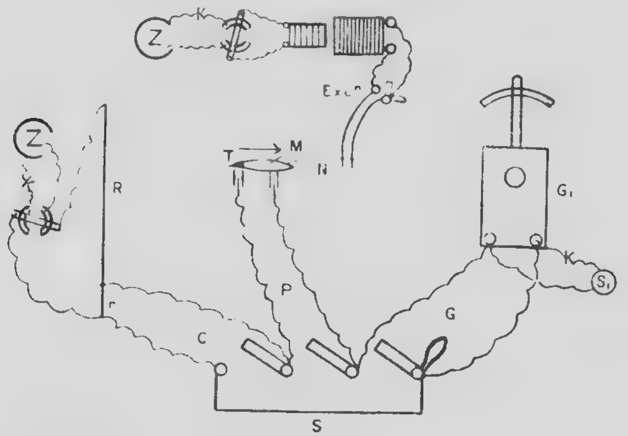

FIG. 13.—Injury current and negative variation of muscle. S, switch-board; P, preparation circuit; M, the muscle; T, its injured end; N, its nerve; the arrow shows the direction of the injury current in the muscle; G, galvanometer circuit; G_1, the galvanometer; S_1, the shunt; C, compensation circuit; R and r, resistances; Exc^n, exciting circuit.

The tendon end of the muscle is then touched with a hot wire, and the electrode reapplied. There is now a very marked difference of potential, the 'current of injury.' The direction of this current is, in the tissue from the injured to the uninjured part, through the galvanometer from the uninjured to the injured part. Hence the injured part is said to be galvanometrically negative to the uninjured, or electro-positive. As the injured part behaves as regards its differences of potential like the zinc in a battery, the term zincative, suggested by Waller, is less ambiguous than either.

It is found that all the tissues of the body behave like muscle in this respect: namely, that an injured part is negative or zincative to an uninjured. The sciatic nerve is then excited, the muscle contracts, and the current of injury is diminished, the contracting part now becoming zincative, and giving a current in the opposite direction to the injury current—the so-called 'negative variation.'

To study the electrical changes in the heart, it is necessary to use either the string galvanometer, or the electrometer. The electrodes can be applied to the isolated frog's heart, when differences of potential will be observed at each beat. The student can also observe the changes in potential produced by the beat in his own heart, leading off from the right and left hands. In all the experiments of the heart the changes in potential are so rapid, that for an accurate observation it is necessary to photograph the excursions of the meniscus of the electrometer, or the shadow of the string, on a rapidly-travelling photographic plate, as the eye is unable to follow its movements.

CIRCULATION

LESSON V

PHYSIOLOGICAL ANATOMY OF THE HEART—ACTION OF VALVES

Physiological Anatomy of the Heart.—Procure the fresh heart and lungs of a sheep, and examine them by Stirling's method. Open the pericardium. Identify the superior and inferior venæ cavæ, bringing the systemic blood to the right auricle, and the pulmonary artery, conveying the blood from the right ventricle to the lungs. Carefully dissect off the pericardium, and identify the pulmonary veins entering the left auricle, and the aorta lying behind the pulmonary artery, carrying the blood from the left ventricle.

Cut through all these large vessels a little distance from the heart.

Action of Valves. (*a*) Have ready two glass tubes 16 mm. in diameter, one 8 cms. long and the other 60 cms., both flanged at one end. Tie the longer tube into the pulmonary artery, ligature the inferior cava and left azygos veins, and tie the shorter tube into the superior vena cava. Connect the other end of this tube with a glass funnel, then pour the water into the funnel. The water will follow the course of the blood, passing into the right auricle, left ventricle and pulmonary artery, and will finally stand at the same level in the latter vessel as in the funnel. Now compress the right ventricle with the hand, so as to imitate the muscular contraction, the water at each systole will rise in the longer tube, and at each diastole will not flow back, being kept from doing so by the semilunar valve.

(*b*) Repeat the above experiment on the left side of the heart, tying the long tube into the aorta, and the short one into one of the pulmonary veins, the other pulmonary veins being ligatured.

(*c*) Cut away the right auricle, and with forceps tear away one of the three cusps of the semilunar valve of the pulmonary artery. Tie the short tube into the pulmonary artery and connect it with the glass funnel as before.

Pour water into the funnel; the semilunar valve now being incompetent, allows water to pass freely backwards into the right ventricle. As the latter fills, the segments of the tricuspid valve float up and come into close apposition, tightly closing the auriculo-ventricular opening.

(*d*) Cut out the aorta with its valves, with a considerable amount of surrounding tissue. Tie the narrow end of a funnel with a short wide flanged stem into the aorta, and pour water into the funnel, the semilunar valves close, allowing no water to pass between the segments. It runs out freely, however, through the coronary arteries. Tie these and observe the appearance of the closed valves, looking down through the funnel, and holding a small electric lamp below the valves.

The same result can be obtained by tying the preparation on the end of a tube and blowing through it. The play of the valves can easily be studied directly, or even projected on a screen.

(*e*) Slit up the aorta and pulmonary arteries, and observe the attachments of the valves and the arrangement of the sinuses of Valsalva, and (in the aorta) the orifices of origin of the coronary arteries. After making the preceding observations, cut open the heart and note the difference in thickness of the walls of the right and left ventricles, the construction of the auriculo-ventricular valves, and their attachments to the musculi papillares by means of the chordæ tendineæ.

The chordæ tendineæ serve to prevent the eversion of the valves into the auricles during systole. Towards the end of systole, when the whole ventricular wall approaches the auriculo-ventricular opening, thereby tending to slacken the chordæ tendineæ, the musculi papillares also contract, thus maintaining the points of origin of the chordæ tendineæ at a constant distance from the auriculo-ventricular ring, and keeping their tension uniform.

LESSON VI

THE ARTERIAL SCHEMA

The investigation of the features of the circulation involves the consideration of a number of physical factors with regard to the motion of fluid in tubes, which can be studied on a model as well as or better than on the living animal. The student should, therefore, make certain that he thoroughly understands the elementary mechanical principles, before proceeding to the consideration of the more strictly physiological factors involved in the circulation.

The schema (Fig. 14) consists of a thick-walled rubber bulb, H, provided at each end with indiarubber valves in wide glass tubes. This represents the left ventricle with the mitral and semilunar valves guarding the orifices into the auricle and into the aorta respectively. The valve, V, leads into the rubber tube, A, with elastic distensible walls, representing the arterial system. This leads into the wide glass tube, C. Part of this

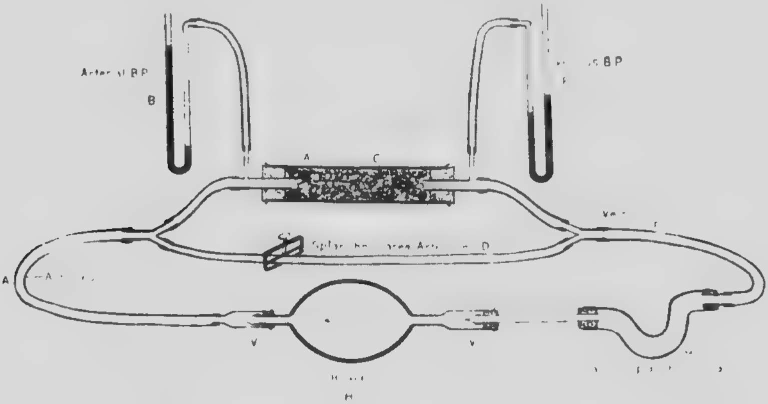

FIG. 14. Schema of circulation. For simplicity the veins of the splanchnic area are placed in series with the systemic veins.

tube is tightly packed with sponges, so as to afford considerable resistance to the fluid passing through the tube. This part, C, represents the arterioles. The part of the tube, C, where the channel is so wide that its resistance becomes almost negligible may be taken to represent the capillaries. From the capillaries another elastic tube, F, representing the veins leads into a large thin-walled rubber tube, G, which corresponds to the large thin-walled veins, *e.g.* of the abdomen. The arterial and venous sides of the schema are also connected by a rubber tube, D, the flow through which can be adjusted by means of a screw clamp, and tubes lead from the arterial and venous sides to two mercurial manometers, B and E, which are provided with a millimeter scale.

Experiment.—With the inflow tube V disconnected from G, and the free ends opening into a basin of water, rhythmically compress the bulb H, so as to fill the whole system with water, driving out the air. It may be necessary to raise the venous tube so as to allow the air-bubbles to escape. Support the glass tube, opening out of the venous system, on the edge of the basin, so that the outflow can be observed. Clamp D, and with the tube, V, dipping under the water, rhythmically compress the bulb at the rate of about fifty times a minute. Note:—

(*a*) The action of the valves, which determine the flow of fluid through the heart in one direction;

(*b*) the high pressure which is produced on the arterial side, and the low pressure on the venous side;

(*c*) the pulsation in the arterial manometer, the almost entire absence of pulsation in the venous manometer;

(*d*) the constant flow from the veins into the basin.

The big fall of pressure from arterial to venous side is an index to the force required to drive the blood through the peripheral resistance in the arterioles. The conversion of the pulsatile flow in the arteries into the constant flow from the veins is also due to the high peripheral resistance, and the consequent accumulation of the force of the heart's beat in distending the arterial wall, so that the elastic reaction of the arterial wall continues to drive on the fluid between the beats.

(*e*) While pumping rhythmically, suddenly pinch the arterial tube, and stop pumping. The arterial manometer is observed to sink slowly, as the stretched arterial wall gradually drives the fluid through the peripheral resistance into the veins.

(*f*) Open the clamp D slightly, so as to simulate dilation of the arterioles, *e.g.* of the splanchnic area, and continue to pump regularly. Note the effect on the arterial and venous pressures, and on the character of the venous flow.

(*g*) Open the clamp widely and continue to pump at same rate. Note that the difference of pressures on the two sides now almost entirely disappears, and there is a pulsatile flow throughout the system.

(*h*) In the body the vascular system is a closed circuit, the veins opening into the heart. Make the schema into a closed circuit by filling up the venous system, and then inserting a glass tube at the end of G into the rubber tube passing into H, taking care to exclude air-bubbles. Note now that there is a slight positive pressure, which is the same throughout the system, the two manometers being at the same height (about 5–10 mm. Hg). Now start pumping as before, with the clamp, D, closed. There is a rapid rise of pressure on the arterial side, and a slight fall of pressure on the venous side. The fall does not, however, correspond to the rise, since the thin-walled veins are so distensible that a very slight change in their internal pressure causes a big alteration in their capacity. They act, therefore, practically as a reservoir, out of which the heart pumps blood into the arterial system. Note that the height of the arterial pressure can be altered (1) by altering rate or strength of the heart beat, (2) by altering the peripheral resistance, *i.e.* by clamping or unclamping D.

Effect of pressure on the veins.—While pumping steadily, gently compress the vein, G. Note the rise of pressure thereby produced, first on the venous side and then on both sides of the system. An analogous effect may be produced in the body by compression of the abdomen.

Effect of gravity.—Allow the heart, H, with its tubes to hang below the level of the table. Note the fall in arterial and venous pressures, the vein, G, becoming more distended under the influence of gravity, *i.e.* of the pressure exerted by the column of fluid between it and the highest part of the system. If the experiment be repeated while the heart is not working, the pressures registered by the two manometers may become negative. Thus, if the heart ceases to beat with a person in the upright position, the whole of the blood in the body will tend to drain down into the dependent parts of the venous system.

The pulse.—While pumping rhythmically at about fifty times per minute, so as to maintain the average pressure on the arterial side of about 100 mm. Hg, press gently with the forefinger on the rubber tubes representing the arteries and veins, and note the pulse in the former. Take a tracing of the pulse by resting a lever on the rubber tube, or by applying to it a Dudgeon's or some other form of sphygmograph, maintaining the beat of the heart as regular as possible.

Take pulse tracings

(1) with the clamp, D, closed ;
(2) with the clamp slightly open ;
(3) with the clamp fully open.

Note the difference in the form of the curve so obtained, which corresponds to the difference obtained in the living body between a high, medium, and low tension pulse.

LESSON VII

DETERMINATION OF BLOOD PRESSURE IN MAN PULSE TRACINGS CARDIOGRAPH

Sphygmomanometer. Two patterns of this instrument can be employed—(*a*) Martin's modification of Riva-Rocci's sphygmomanometer, and (*b*) Leonard Hill's pocket sphygmometer.

(*a*) This instrument consists of an armlet made of a distensible rubber bag with an external leather coat, which can be distended by an air-bulb, so as to exert any given pressure on the arm. Connected with the bag is a mercury manometer, which reads off the pressure directly.

Experiments.—To measure the blood pressure in any given artery, *e.g.* brachial, place the armlet around the middle of the upper arm; place the fingers of one hand on the radial artery and raise the pressure in the armlet until the radial pulse is no longer felt; read the pressure required in the manometer. Then let the air slowly escape from the bag, until the pulse just again becomes perceptible, and read the manometer again; the mean of these two readings will give the systolic pressure in the brachial artery. Repeat the experiment two or three times

Compensations for the Effect of Gravity. Take the read-in the brachial artery with the subject—(*a*) standing; itting up, (*c*) lying down; (*d*) inverted.

Effect of Vaso-dilation.—Let the subject then place his ad in hot water, and again read the pressure.

Effect of Gravity.—With two armlets take the pressure nultaneously in the arm and leg, with the subject—(*a*) standng; (*b*) lying flat.

In the first case, measure also the difference in height of he two armlets.

Effect of General Vaso-constriction and Dilation.—Compare the pressure in the brachial artery—

(*a*) Under normal conditions;
(*b*) While holding the breath;
(*c*) After the inhalation of 3 minims of amyl nitrite.

The same experiments can be performed with Hill's pocket sphygmometer. In this instrument the artery is compressed by a rubber ball covered by a silken bag; the pressure employed is read off on the gauge, and the disappearance of the pulsation estimated by the fingers on the distal part of the artery.

The Sphygmograph.—The instrument used is the pattern known as Dudgeon's. It consists of a button, which is placed over the radial artery; this is connected by a system of levers, which amplify the movement, to a writing-point; a smoked strip of paper is drawn by means of rollers at a uniform rate beneath the writing-point. The clockwork which drives the rollers is started and stopped by means of the lever at the top of the instrument.

An arrangement is also provided by which the pressure over the artery can be varied by turning a milled head connected with a heart-shaped cam. The milled head is graduated in ounces Troy.

There is also a strap and clamp by which the instrument is attached to the arm.

Experiments.—To obtain a record, feel for the radial artery, and mark its position with a pencil at the level of the lower end of the radius. Place the button of the instrument accurately in this position, and fasten the strap around the wrist moderately tightly, the clockwork being directed up the arm. A movement of the lever will probably be visible. Turn the milled head from zero until the largest excursion of the writing-point is obtained. Now, having previously ascertained that the clockwork is wound up, place a strip of smoked paper between the rollers, see that the writing-point lies freely on the paper, start the mechanism, and take a tracing. These vary considerably in appearance with arterial tension, and the amount of tissue lying between the artery and the surface, mostly, however, showing a rapid rise and a more gradual fall of pressure, the middle of which shows a secondary wave—the *Dicrotic wave.* The effects on the tracing of various conditions, *e.g.* holding the breath, may be tried, also the action of drugs, such as amyl nitrite or nitroglycerin.

The Cardiograph.—The usual instrument employed is that of Marey. It consists of a receiving tambour provided with a button, which is placed over the 'apex beat,' and a recording tambour with a lever bearing a writing-point, which traces on a smoked drum. A thick walled rubber tube connects the two, provided with a valve, so that the air pressure in the system can be regulated.

Experiment.—Feel for the cardiac impulse in the fifth intercostal space, 3·5 inches from the middle line. It varies somewhat with posture, and in different individuals. It is sometimes exactly behind the fifth rib, and in such persons a good tracing cannot be obtained. Adjust the pressure of the button on the chest wall, and the amount of air in the two tambours, until the best excursion of the lever is obtained, and take a tracing of the impulse.

LESSON VIII

CONTRACTION OF FROG'S HEART—SEQUENCE AND RHYTHM OF BEATS—FIRST AND SECOND STANNIUS LIGATURE—EFFECT OF HEAT AND COLD

Experiments.—Pith a frog and lay it on its back. Remove the skin from the front of the chest, open the abdomen and, cutting upwards, carefully remove the sternum. Open the pericardium and excise the whole heart, cutting through the two aortæ and the great veins. Examine the excised heart. It continues to beat rhythmically, the contractions beginning at the sinus venosus, the auricles contracting next, and lastly the ventricle. The rhythm therefore is sinus-auricles-ventricle. Proceed to record the beat as follows, using Gotch's apparatus (Fig. 15). This consists essentially of a small glass jar with inlet and outlet tubes, a shelf of cork fits stiffly about half-way down the jar, and is pierced to allow the passage of a brass rod. To the upper end of this brass rod is connected the recording lever.

To fix the heart in the apparatus the tip of the ventricle is transfixed by a bent needle or fine pin, to which is attached a fine thread. Another pin is passed through the aortæ, the heart is fastened to the cork shelf with this, and the thread tied to the suspension lever. The glass jar is then filled with Ringer-Lockes' fluid.[1]

Record the movements of the lever on a slowly moving drum. The pin fixing the heart to the cork plate can be passed through the veins instead of the aortæ. In this case the movements of the sinus and auricles are recorded as well as the ventricle, but the preparation will seldom continue in good condition for any length of time.

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[1] This fluid is composed of—NaCl 0·7; $CaCl_2$ 0·025; KCl 0·035; $NaHCO_3$ 0·01; Dextrose 0·06; water 100·00 parts. The water must be distilled in glass apparatus, and be free from NH_3. $NaHCO_3$ is added immediately before use, and the fluid saturated with oxygen.

The beat of the heart can also be recorded *in situ* in the following manner. Prepare the pithed frog as before. When the sternum is removed, and the pericardium opened, pass the bent pin and thread through the apex of the ventricle, gently lift up the heart by this thread, and snip through the frænum. The frog is now laid on the cork plate, P, and the thread is attached to the simple lever (L) as in the illustration, Fig. 16. The beat is recorded on the drum as before.

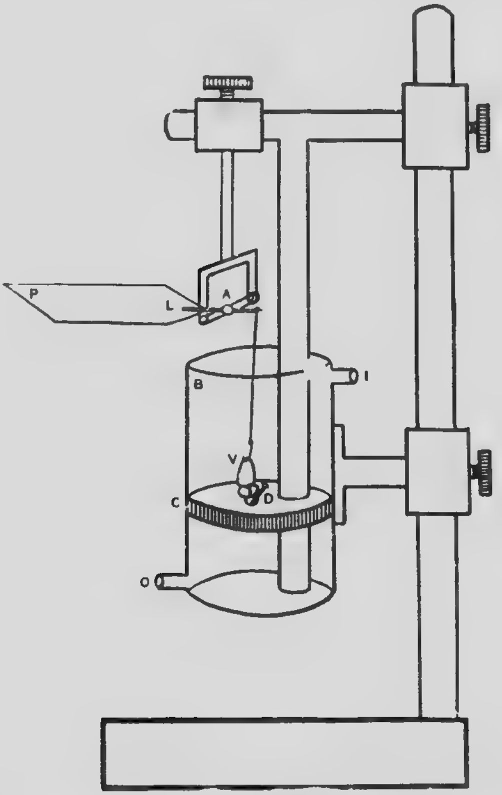

FIG. 15.--Gotch's apparatus for isolated frog's heart. B, glass vessel; O and I, outlet and inlet tubes; C, shelf of cork; V, ventricle; L, lever; A, its axle; P, writing point.

First Stannius Ligature.—Take a tracing as described. Pass a thread under the aortæ, bring the two ends to the front, and tie them tightly over the junction between the sinus venosus and auricles. The exact place where the ligature is to be applied is marked by a cresentic line a little lighter in colour than the auricles or sinus. When the ligature is correctly applied the auricles and ventricle usually stop beating in diastole, the sinus continuing to beat at the previous rate. Leave the preparation alone for a minute or two. If the standstill is not complete, apply a second ligature a little nearer to the auricles, if this is not successful take another heart.

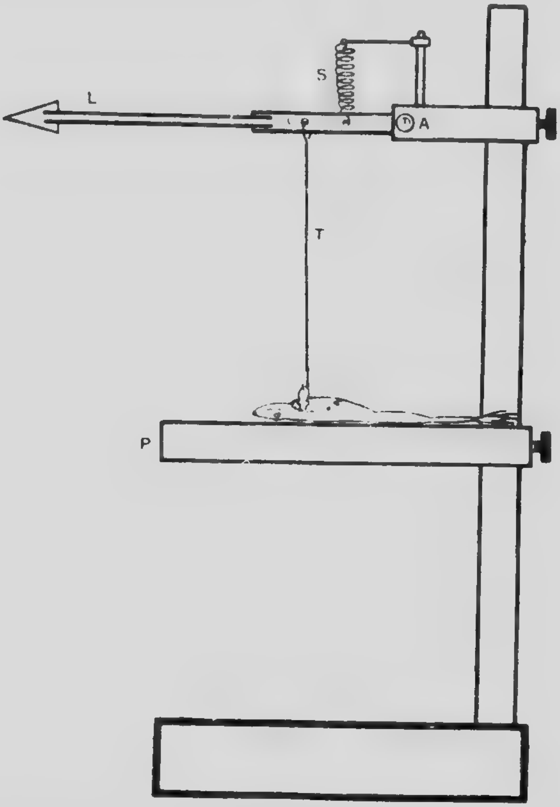

FIG. 16.—Simple heart lever. The heart pulls against the spring, S, by means of the thread, T.

Set up the apparatus for recording a single muscle twitch (as in Fig. 10), but leaving the drum out of the circuit, placing the exciting electrodes on the surface of the ventricle. It will respond to each induction shock with a single contraction. Measure the time relations of the curve. Vary the strength of stimulus, and note that the ventricle gives either a maximum contraction or none—the heart beat is 'all or nothing.'

The Stair-case.—Again leave the preparation untouched for two or three minutes. Re-arrange the circuit so as to apply single induction shocks by hand. Then excite the ventricle by shocks repeated at regular intervals—say every four or five seconds. The successive contractions of the ventricle will be each a little greater than the last, up to about the fifth or sixth contraction—the so-called 'stair-case.' This gradual increase of response to a maximal excitation is found in all the tissues of the body so far as they have been investigated.[1]

The Second Stannius Ligature.—If the preparation has remained so long without beating spontaneously it can be used for a final experiment. Tie a thread tightly around the auriculo-ventricular junction—the second Stannius ligature. The ventricle will then commence to beat rhythmically, the auricles remaining quiescent.

Effects of Heat and Cold.—Make a fresh preparation, using the Oxford apparatus. (Fig. 15.)

Record the contractions on a slowly revolving drum, the heart being immersed in Ringer's fluid at room temperature. Next allow Ringer's fluid which has been cooled at 4° to flow through the apparatus and note the difference in the record. When the record has become even again, change the cooled solution for some which has been warmed to 25°, and note the alteration in the rhythm of the beats.

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[1] It does not occur if the tissue has been previously acted on by atropine.

LESSON IX

FROG'S HEART—EFFECT OF MUSCARINE—ATROPINE—PILOCARPINE—DIGITALINE—VAGUS—NICOTINE—BILE

Muscarine and Atropine.—Record the beats of a frog's heart as in the previous lesson. At a convenient point in the tracing apply a few drops of 0·1 per cent.[1] solution of muscarine and observe that both the rate and force of the contractions diminish, the heart finally coming to a stand-still in diastole. A very strong stimulus either electrical or mechanical will be required to make the heart beat in this condition. When this result has been obtained, bathe the heart in a few drops of 0·5 per cent. solution of atropine. The heart will gradually begin to beat again, usually more forcibly and more rapidly than at first.

Pilocarpine and Atropine.—Take a fresh heart and repeat the previous experiment, using 0·5 per cent. solution of pilocarpine nitrate. The action closely resembles that of muscarine. Apply atropine ; the heart beats again.

Digitaline.—Take a fresh heart and apply 0·1 per cent. solution of Digitaline. The heart becomes slower in rhythm and contracts to smaller dimensions in systole, while it does not dilate so fully in diastole. The ventricle is therefore whiter during systole than before. The heart remains contracted longer and relaxes less perfectly than before, so that the rhythm is slower.

Later, relaxation becomes still more imperfect, and the ventricle may only relax once for every two relaxations of the auricles, and finally it stops in systole. The auricles stop also ; as they are unable to empty themselves into the contracted ventricle they are distended with blood. If the vagus centre in the medulla is intact these events may at first be complicated by a slowing and dilation of the ventricle, due to the action of the vagus.

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[1] All these solutions to be made up with normal saline or Ringer-Locke's fluid.

The Vagus.—Pith a frog. Remove the skin from the front of the chest, cut through the clavicles on either side and remove the sternum, taking care not to injure the structures below in so doing. Cut through the platysma myoides very cautiously. Remove the threads of connective tissue from the angle of the jaw, when the thin strip of the petro-hyoid muscle will be seen. This muscle arises from the base of the skull, and is inserted into the posterior cornu of the hyoid bone, and is the guide to the vagus nerve (see Fig. 17). Crossing the muscle and running forwards will be seen two nerves, the glosso-pharygneal and the hypoglossal, the latter the more mesially placed of the two. Along the lower border of the muscle run three structures. From above downwards these are—1, the lingual nerve; 2, the carotid artery; 3, the vagus. Remove a little of the filmy connective tissue surrounding these structures, and isolate the vagus as far as possible, taking great care not to damage it. Pass a fine silk thread around the nerve, tie it as high up as possible and cut through the nerve above the ligature. Three or four

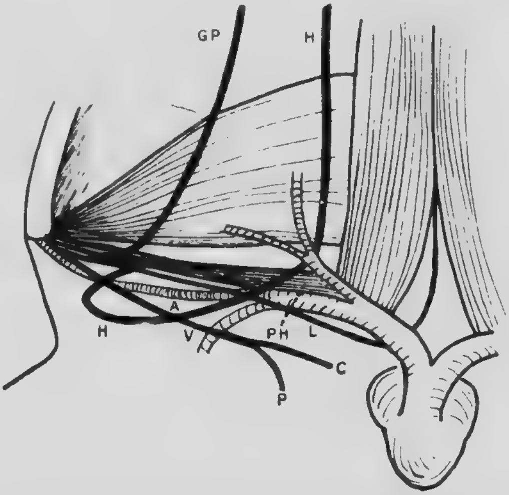


Fig. 17.—The course and relations of the vago-sympathetic in the frog. (After Brodie.) v, vagus; p, pulmonary branch; c, cardiac branch; l, laryngeal branch; h, hypoglossal; gp, glossopharyngeal; a, carotid artery; ph, petro-hyoid muscle.

millimetres of nerve can be isolated in this way. Special care must be taken not to stretch the nerve. Remove the frog to the frog plate and record the beat of the heart by the suspension method (Fig. 16, p. 40). Place the nerve on a pair of fine pointed electrodes, and stimulate with tetanising shocks.

According to the strength of the stimulus, the heart will be slowed, or will stop in diastole. When the stimulus ceases, the heart will often beat more rapidly and more forcibly than before. The student will note that in this experiment he has been stimulating the combined vago-sympathetic trunk.

Nicotine.—Apply a few drops of 0·1 per cent. solution of nicotine. The effect on the beat is usually to cause **first** a slight slowing, and later on a slight increase in both rate and force of beat.

Stimulate the vagus. No stopping or weakening of the beat is seen. Usually there is a slight augmentor effect due to the sympathetic fibres. Stimulate the sinus directly. A typical stand-still follows. Apply atropine to the heart. Vagus stimulation has naturally the same result as before; stimulation of the sinus now produces no stoppage.

Bile.—To any of the hearts that are still beating apply the bile obtained from the gall bladder. The beats will rapidly diminish in force and rate, and the heart will stop in systole. The same effect, differing only in degree, is to be seen in patients suffering from jaundice; it is mainly due to the bile salts.

LESSON X

THE CIRCULATION IN A DECAPITATED ANIMAL BLOOD PRESSURE—EFFECT OF ADRENALIN

If when an animal is killed by decapitation, the carotid and vertebral arteries be ligatured so as to prevent the whole of the blood in the body draining away, the heart will go on beating, and sufficient circulation may be maintained in the hinder parts of the carcase, to preserve the vitality of its tissues for several hours. Under these conditions, these tissues may be made the subject of experiment in the same way as a frog's nerve-muscle preparation. It is necessary, of course, to maintain the due aeration of the blood by rhythmically blowing up the lungs with air (artificial respiration), and care must be taken to keep the tissues at the normal body temperature. For this purpose the carcase is fixed on a tin box, which is warmed by means of an electric lamp in its interior, and the air which is pumped into the lungs by means of a bellows is also warmed before it enters the trachea.

The animal is killed under chloroform or ether anæsthesia, and artificial respiration arranged by the demonstrator. With a scalpel make an incision two inches long in the middle line of the neck, beginning at the point at which the tube is tied into the trachea. Divide the connective tissue beneath the incision, exposing the inner margins of the two sterno-mastoid muscles. Pull the right sterno-mastoid aside, dividing the connective tissue if necessary. At the bottom of the groove between this muscle and the sterno-hyoid and sterno-thyroid muscles, which lie immediately on the trachea, is seen the carotid sheath, in which the artery may be seen or felt to be beating. Pick up the carotid sheath with forceps, open it, and with scissors prolong the opening upwards and downwards. In the same way (that is to say, by picking up the connective tissue and cutting it with scissors) free the carotid artery from its surroundings. Lying alongside the carotid artery will be seen two nerves, a larger white nerve, the vagus, and a thinner nerve, somewhat more greyish in appearance, the cervical sympathetic. Tie a thread round the vagus, leaving the ends long. Knot the ends. Now place two threads round the carotid artery about three-quarters of an inch apart. Tie the one nearest the head with a double knot, leaving the ends long. These should be knotted. Tie the other thread singly, leaving it loose. With the loose ligature pick up the artery and clamp it as near the heart as possible, with a pair of bull-dog forceps. Now, holding the artery up by means of the upper thread (which has been tied tightly), snip a small opening in it with a pair of fine scissors. Into this opening insert a cannula (François-Franck) of the form shown in the figure.

Now connect the side tube of the cannula by means of a thick-walled rubber tube to the open end of a mercurial manometer, having previously filled the tube through the end tube of the cannula with saturated sodium sulphate solution. Arrange the float in the manometer so that its upper end will write on the blackened surface of the drum, the drum being set to move at a slow rate (1 mm. per second). With a syringe inject sodium sulphate solution into the cannula and tube, until there is a pressure in the system of 100 mm. Hg (4 inches), as judged from the difference in heights of the mercury in the two limbs of the manometer. Clamp the end tube, and release the clamp on the artery. The mercury will drop till it shows a pressure of about 60 mm. Hg, and will oscillate about this pressure, rising and falling with each heartbeat, as well as with the respiratory movement.

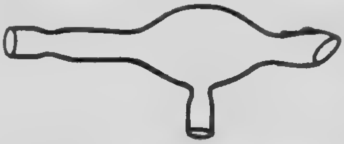


FIG. 18.—François-Franck Arterial Cannula.

Allow the drum to revolve, and take a tracing of the normal blood-pressure. Take tracings also under the following conditions :—

(*a*) While stimulating the peripheral end of the right vagus with a Faradic current. Try the effects of different strengths of stimulus.

(*b*) Stop the artificial respiration. If the spinal cord is not too much depressed by the removal of the higher parts of the nervous system, a rise of pressure may be obtained, attended with spasmodic movements of the muscles as a result of asphyxia. When the pressure begins to fall by reason of heart failure, put on the artificial respiration again.

(*c*) Insert the terminals of the exciting electrodes into the open end of the spinal canal, so as to excite the vasomotor tracts of the cord, and produce general vascular constriction.

(*d*) Inject one minim of adrenalin solution (1 in 1,000) into the external jugular vein by means of a hypodermic syringe. Repeat this experiment after complete destruction of the cord by passing a wire down the spinal canal.

LESSON XI

THE ACTION OF THE HEART—INHIBITORY AND ACCELERATOR NERVES—HEART SOUNDS

This may be studied in the carcase of a decapitated cat in which the vessels of the neck have been ligatured as described in the last lesson. Make a longitudinal incision in the middle line along the whole length of the sternum; then, keeping carefully in the middle line, with a pair of strong scissors or bone forceps cut through the chest wall. Care must be taken not to injure the internal mammary arteries. If any vessel is injured it must be at once clamped with a pair of artery forceps. The two sides of the chest wall are fastened apart by weighted hooks, thus exposing the heart with its pericardium. Pick up the pericardium with forceps, open it, taking care not to wound the heart, and continue the incision along the whole length of the heart. Note the sequence of events in the cardiac contractions, and the movement of the ventricles as they contract.

Attach the right auricle and the apex of the ventricle, by means of threads with hooks, to two levers, which are arranged to write one over the other on a blackened surface. If any difficulty is experienced in getting the blackened surface sufficiently near to the carcase, the two threads from the auricle and ventricle may be attached to two tambours. From these tambours tubes are carried to two other tambours provided with levers writing on the drum. (Note.—If necessary, the record of the contractions of the heart may be omitted, tbe student trusting to ocular inspection for determining the changes brought about by the stimulation of the cardiac nerves.)

Inhibitory nerves.—Expose the vagus in the neck, and stimulate it with varying strengths of current. Note the change in rhythm and force of contraction of the auricle, and the change in rhythm of the ventricle. The incidence of the effect on the two cavities may vary, according to the strength of stimulus, and according as the right or left vagus is excited.

Press on the abdomen, and note the greater amplitude of the contractions brought about by the increased diastolic filling of the heart cavities.

Stimulation of the Accelerator Nerves.—To expose these nerves, prepare the sympathetic in the neck as it runs at the back of the carotid sheath, and tie a ligature round it. Holding the ligature in the left hand, trace the nerve down into the thorax, where it passes beneath the subclavian vein. Tie two ligatures round this vessel, and divide it between the ligatures. The subclavian artery will now be exposed. The cervical sympathetic apparently divides into two branches as it passes round the subclavian artery, and by raising the subclavian artery, these branches, which form the annulus of Vieussens, are seen to pass into the stellate ganglion, a large white ganglion lying on the neck of the first rib. From the annulus, or from the cervical sympathetic immediately above, fibres are given off to the heart. The accelerator fibres may be stimulated by placing the electrodes under one or both branches of the annulus. An effect on the rhythm would only be noted if the heart is not already beating at its maximum rhythm.

Heart Sounds.—Disconnect from the heart the threads which have been used for recording. With the binaural stethoscope listen to the sounds of the heart, and compare them with the sounds heard on listening to your own heart or that of a friend

With a pair of scissors cut through the large veins and arteries which enter and leave the heart. Lift the heart out of the chest, note that its cavities still continue to beat in orderly sequence. Now listen to the heart again, placing the end of the stethoscope directly on the ventricle. The second sound will be found to have disappeared, but the first sound is very little altered, although the circulation through the heart has ceased. The heart-beat gradually gets less frequent as the heart cools. Without waiting for the beats to come to an end, stimulate the ventricle directly with strong interrupted shocks. The rhythmic beat ceases, and the heart passes into *delirium cordis*, in which all the fibres contract irrespective of each other. In the normal animal this delirium is never recovered from. It is the cause of death from strong electric shocks or lightning stroke, and may also come on spontaneously as a result of disease of the coronary arteries.

LESSON XII

VASO-MOTOR SYSTEM—SYMPATHETIC—DEPRESSOR—SPLANCHNIC—ASPHYXIA: DEMONSTRATION

Function of the Cervical Sympathetic Nerve.—For this purpose a white rabbit, or one with white ears, should be chosen. The rabbit is anæsthetised with ether, and a subcutaneous injection of chloral hydrate (0·5 grs. per kilo.). Make an incision three inches long in the middle line of the neck, expose the trachea and pass a thread loosely round it, so that tracheotomy may be performed if necessary later. On one side separate the sterno-mastoid from the sterno-hyoid and sterno-thyroid muscles, exposing in this way the carotid artery. If the carotid artery be now lifted up by means of the surrounding connective tissue, three nerves will be seen accompanying it: 1, a large white nerve, the vagus; 2, a smaller greyish nerve lying at the back of the artery, the cervical sympathetic; 3, a very small white nerve, the depressor nerve. If this were traced up, it would be found to connect at the upper part of the neck by two branches with the trunk of the vagus, and with the superior laryngeal nerve. Do not, however, try to dissect it at this stage. Pass a fine silk thread loosely round each of the three nerves. Now tie a thread tightly round the sympathetic nerve, and divide the nerve on the heart side of the ligature. On holding up the ears of the rabbit, the vessels of the ear on the side in which the sympathetic has been cut will be seen to be dilated as compared with those of the opposite side. While the ears are being held up, lift the cut end of the sympathetic

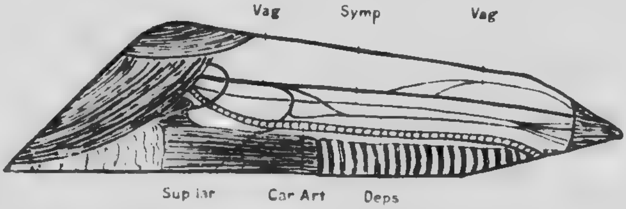


FIG. 19.—The nerves in the rabbit's neck. (After Cyon.) Vag., vagus; Sup. lar., superior laryngeal; Symp., sympathetic; Deps., depressor; Car. art., carotid.

out of the wound, and stimulate it with a Faradic current. The vessels will be seen at once to contract, so that the whole ear becomes bloodless as compared with the opposite side. Note also the changes in temperature caused by these vascular changes.

Function of the Depressor Nerve.—On the side on which the sympathetic has been cut insert a cannula into the carotid artery, and connect it with a manometer so as to record the blood pressure on a kymograph. While taking the blood pressure tie ligatures tightly round both depressor nerves. A slight temporary fall of blood pressure may be brought about, but no lasting effect will be produced. Now stimulate the central end of either depressor with a fairly strong Faradic current. Note the fall in the blood pressure, and also the decrease in the frequency of the heart beats. The fall might be due to reflex cardiac inhibition or to reflex dilation of the blood vessels. Now divide both vagi and stimulate the depressor again. A fall of pressure occurs as before, but there is no change in the frequency of the heart beats, showing that the chief part of the lowering of blood pressure is due to reflex vaso-dilation

Function of the Splanchnic Nerve.—Open the abdomen in the middle line and expose the splanchnic nerve on one side, as it passes from the crus of the diaphragm to the semilunar ganglion. Ligature the nerve, cut it and place it on shielded electrodes. Take another record of the blood pressure and while doing so, stimulate the splanchnic electrically. Note the rise in the blood pressure, due to vaso-constriction in the abdominal viscera. Repeat the experiment with the abdomen open. Note the pallor of the intestines produced during the constriction.

Effect of Sensory Stimulus.—The animal being thoroughly anæsthetised with chloral, inject into the jugular vein sufficient curare to paralyse the skeletal muscles. Open the trachea, insert a cannula and start artificial respiration. Expose an ordinary sensory nerve, such as the anterior crural or sciatic nerve, and stimulate its central end while recording the arterial blood pressure. Note the change produced.

Asphyxia.—Stop the artificial respiration, and note changes in the blood pressure produced by asphyxia. When the blood pressure has been reduced nearly to zero, open the chest, and observe the dilated condition of the heart cavities.

LESSON XIII

DEMONSTRATION OF VASO-DILATOR NERVES

A dog is anæsthetised with morphia and A.C.E. mixture. The chordo-lingual nerve is exposed, cut, and placed upon shielded electrodes, as described in Lesson XVI. A cannula is inserted into the submaxillary duct. Now prolong the incision from its hinder end outwards, parallel to the ramus of the lower jaw, so as to expose the large veins running over the submaxillary gland. Tie the internal maxillary and facial veins, on a level with the anterior border of the gland, and tie also the sublingual vein, about an inch peripherally to its junction with the facial vein. Tie also any smaller veins draining the skin and superficial tissues into the veins already mentioned. The vein which returns all the blood from the submaxillary gland is somewhat inconstant in its course, but in most cases it joins one of the veins already tied on its deeper surface. All the blood therefore which is returning along these three veins to the external jugular vein has been shut off by the ligatures except that coming from the submaxillary gland. Now inject, intravenously, a solution of hirudin (1 centigramme per kilo.) to render the blood incoagulable. Insert a cannula into the distal end of the external jugular vein near the point where the internal and external maxillary veins join, and arrange the end of the cannula so that the blood coming from it drops on to a drop recorder (see Fig. 22, p. 61). Arrange the lever of the tambour connected with the drop recorder to write on a blackened surface. A time marking must also be taken. Record the flow for five minutes.

1. Then stimulate the chorda tympani and note the great increase in the velocity of the outflow of the blood.

2. Expose the vago-sympathetic in the neck of the same side, and while recording the outflow from the gland, stimulate its peripheral end. Note the diminution or sometimes complete stoppage of the blood, due to vaso-constriction.

3. Repeat the stimulation of the chorda tympani after a sufficient dose of atropin has been administered to paralyse its secretory fibres.

LESSON XIV

VASO-MOTOR SYSTEM—USE OF THE PLETHYSMOGRAPH—CAPILLARY CIRCULATION DEMONSTRATIONS

In investigating the variations in the blood supply to any part of the body, it is necessary always to combine with an observation of the local changes, a record of the general blood pressure, if we would understand the part played by local and general changes respectively in producing the variation in local blood flow. The anæsthetised animal (dog or cat) is placed on its belly. An incision is now made on the right side four inches long, half inch below and parallel to the last rib. Divide the superficial connective tissue, securing any vessels which may be cut, and expose the sheath of the erector spinæ. Open the sheath by incising it longitudinally, on each side of the wound, for a couple of inches. Retract the muscle strongly with a blunt copper spatula, separating it from the anterior or ventral layer of the sheath. Open the sheath by an incision, or by scratching an opening into it about half an inch long, just external to its insertion into the transverse processes, taking care not to cut the last dorsal nerve and artery. It is sometimes advantageous to doubly ligature this vessel in order to obtain more room. Insert the two forefingers into the opening just made, and enlarge it forcibly. On pressing the kidney, which will be thus exposed, downwards and outwards, the suprarenal gland comes into view, with a vein lying superficial to it. The vein is thin walled and easily torn, an accident which puts an end to the operation. Behind this vein, running from the suprarenal gland to the crus, of the diaphragm, is the splanchnic nerve. This should be ligatured and divided as near as possible to the crus, and then placed on shielded electrodes. The wound can then be sewn up, leaving the ends of the electrodes projecting. Turn the animal over. Connect the carotid artery with a mercurial manometer, and place both vagi on threads so that they may be tied later. Open the abdomen in the middle line. Draw out about two feet of small intestine. Double ligature the intestine at each end of the loop, and cut it between the ligatures, and carry the incision along the mesentery as far as its attachment to the back of the abdominal cavity. Now introduce the loop of intestine into the intestinal plethysmograph, handling the loop as little as possible. Cover the plethysmograph with a glass plate, making the joints tight by means of vaseline. Clamp it in position, so as to avoid kinking the mesenteric vessels, and connect it by rubber tube with a piston recorder, which is arranged to write below or above the blood pressure manometer. Record the simultaneous changes in the volume of the intestine and in the general blood pressure produced by (*a*) stimulation of the splanchnic nerve, (*b*) stimulation of the peripheral end of either vagus, (*c*) stimulation of the central end of either vagus, (*d*) injection of nicotine, (*e*) injection of adrenalin.

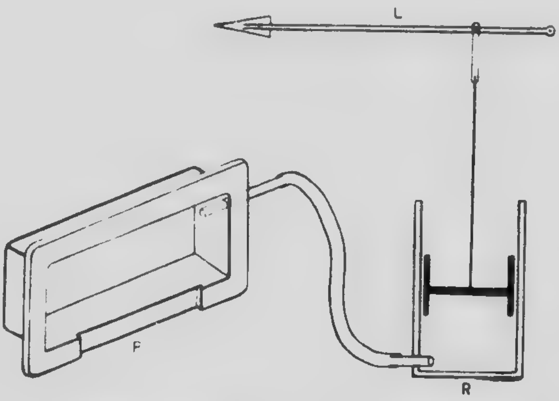


FIG. 20.—Schäfer's Plethysmograph. F, box for organ; R, piston recorder; L, lever.

Capillary Circulation.—Kill a frog by destroying its brain, and plug the cranial cavity with a wooden match to prevent loss of blood. Wrap the frog in a moist cloth and fix it with tape on a board. At the lower end of this board is a small round hole. Draw one of the hind limbs out of the cloth, tie threads round two of the toes, and fix these threads in notches at the edge of the board so as to extend the web between two of the toes just over the opening in the board. Place the board on the stage of the microscope. Examine the web with a low power. If the blood is not circulating through the smaller vessels the web has probably been stretched too tightly, and the threads must be slightly relaxed. Then examine with high power. Identify the arteries, capillaries and veins, noting where the blood is flowing from large to small vessels, and where it is flowing from smaller to larger vessels. In the arteries note (*a*) the pulsating stream, (*b*) the rapid, axial stream containing the red corpuscles and the lighter peripheral zone near the walls of the vessels. In a small vein note the constant stream, the slower current, and less marked peripheral zone. In the capillaries note the frequent anastomoses, the two different kinds of corpuscles, the elasticity of the corpuscles, and their change in shape when passing or turning a corner, and the tendency of the white corpuscles to collect towards the periphery of the vessel and to adhere to its walls.

Inflammation.—Note the changes in the circulation after applying an irritant such as croton oil or turpentine to the skin. Of chief interest among the phenomena observed is that known as diapedesis, namely, the emigration of the white blood corpuscles from the vessels. These changes are still better seen in a vessel of the mesentery.

(If time allows, the effects of stimulating the sciatic nerve on the vessels may be observed, the skeletal muscles having been paralysed by a previous subcutaneous injection of curari. As the sciatic nerve conducts vaso-constrictor fibres to the vessels, stimulation of this nerve causes the arteries to diminish in size, and the circulation is consequently slowed, or even stopped.)

LESSON XV

THE PRODUCTION OF LYMPH: DEMONSTRATION

For this purpose it is better to use a dog, owing to the greater size and toughness of the thoracic duct in this animal. It is anæsthetised with morphia and with A.C.E. mixture. A cannula is placed in the femoral artery, and connected with a mercurial manometer. Another cannula is placed in the right jugular vein for subsequent injection of various substances. To expose the thoracic duct, a skin incision is made, 3 inches long, starting from a point at the lower border of the neck, midway between the top of the sternum and the point of the left shoulder, and prolonged thence up the neck to the level of the cricoid cartilage. The connective tissue is then divided, until the external jugular vein is exposed. From its near side a vein will be seen passing to the thyroid gland, and accompanied by an artery. These vessels are double ligatured and cut. The vein is then pulled outwards and the carotid sheath exposed. Open the sheath by picking up the connective tissue composing it and cutting it with scissors, taking care to keep outside the small internal jugular vein. Insert the left forefinger into the opening thus made, forcing it down the sheath so as to raise it away from the vessels. The right forefinger is inserted into the same opening, passed down so as to press the vessels downwards and away from the left forefinger. Keeping the two fingers in the position thus imparted to them, the thoracic duct will be seen as a translucent, colourless vessel passing obliquely across the deeper parts of the wound, up to the point where the left forefinger is pressing on the connective tissue and lower end of the jugular vein. Keep the left forefinger in its position. With fine curved forceps slightly separate the duct from its bed, and pass under it a fine silk ligature which is tied. A little lower down pass another silk ligature, which is loosely tied once. Care must be taken not to dissect out the whole duct, otherwise it shrivels up into a thread directly it is opened. It is simply freed from its bed at the parts where the ligatures are applied. Now take the glass cannula, hold it in the mouth, and with a sharp pair of scissors make an opening in the duct between the two ligatures. The lymph at once rushes out of the opening, and before the duct has time to collapse the cannula is inserted. An assistant then ties the loose ligature around the cannula so as to secure it. Arrange the cannula so that its weight does not kink the duct, and incline the head and neck of the animal slightly to one side so that the lymph flows away readily.

The lymph has to be collected in graduated tubes holding 10 cc.s, and the amount issuing during each ten minutes is measured. Note the lymph flow under the following circumstances:

1. Normal.
2. While the abdomen is kneaded.
3. While passive movements are made of the lower extremities.
4. During obstruction of the portal vein.
5. During obstruction of the inferior vena cava. (This is effected by passing a sound with a rubber balloon tied on it down the left jugular vein into the inferior cava, and when in position distending the balloon by injecting a previously measured quantity of water.)
6. Intravenous injection of a boiled extract of leeches, or of mussels, or of commercial peptone (first class of lymphagogues).
7. Intravenous injection of a strong solution of dextrose (30 g. dextrose dissolved in 30 cc.s water), (second class of lymphagogues of Heidenhain).

DIGESTION

LESSON XVI

PHYSIOLOGY OF SALIVARY AND PANCREATIC SECRETION—JAUNDICE

Secretion of Saliva. *Demonstration.*—The main facts with regard to salivary secretion can be most easily demonstrated on the submaxillary gland of the dog. The animal being anaesthetised with morphia and with chloroform or A.C.E. mixture, an incision is made four inches long in the middle line from opposite the canine teeth as far back as the angle of the lower jaw. The mylo-hyoid muscle is thus exposed. Cut carefully across the fibres just to one side of the middle line, taking care not to incise the genio-hyoid muscle. Turn the cut end of the muscle outwards and separate the subjacent structures from it as far back as the angle of the jaw. Two nerves will then be seen (see Fig. 21), both coming in from the deeper part of the wound, and running up to supply the anterior part

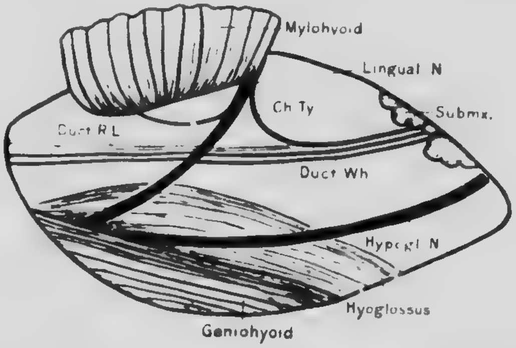


FIG. 21. The submaxillary region in the dog. Submx., the submaxillary gland; Duct. Wh., its duct; Duct. R.L., retrolingual duct; Ch. Ty., chorda tympani.

of the tongue. The most anterior of these is the lingual nerve. In the deep part of the wound the latter will be seen to give off backwards a small branch, the chorda tympani nerve, which runs back along the submaxillary duct to the gland. Pass a ligature round the lingual nerve, some distance behind the point at which it gives off the chorda tympani. Tie the ligature tight and cut the nerve so that the conjoint chordo-lingual nerve can be lifted up for stimulation. Two ducts, from the submaxillary and retro-lingual glands, will be seen crossing the lingual nerve and running to the anterior extremity of the wound. The larger of these is the submaxillary duct. Pass a ligature round this duct and tie it. Now stimulate with a weak Faradic current the chordo-lingual nerve for a few seconds. Secretion of saliva is caused, which distends the duct and therefore facilitates its further manipulation. Half an inch behind the level of the first ligature clean the duct of its surrounding connective tissue and pass a ligature loosely round it. Now stimulate again for a few seconds, then open the duct between the two ligatures and while the saliva is flowing from the wound in the duct insert a cannula, taking care not to push the latter between the duct and the surrounding connective tissue. The cannula is then tied in.

1. Stimulate the chorda tympani for fifteen seconds and measure the amount of saliva produced during the time of stimulation, and during the subsequent fifteen seconds. Repeat this stimulation several times.

2. Expose the vago-sympathetic in the neck. If possible separate the vagus from the sympathetic fibres and pass a ligature round the latter. Now stimulate the head end of the sympathetic. Note the effect on the secretion of saliva.

3. Insert a cannula in the carotid artery, and connect it with a mercurial manometer arranged to write on the blackened surface of a kymograph. Connect the cannula in the submaxillary duct with another mercurial manometer of fine bore, and arrange this latter to write on the kymograph below the blood pressure record. Now stimulate the peripheral end of the chorda tympani nerve repeatedly, for periods of ten seconds at a time. Note that the mercury in the manometer attached to the duct rises with each stimulation, until it may considerably exceed the pressure indicated by the manometer attached to the carotid artery.

4. Inject 1 or 2 milligrammes of pilocarpine, and note the effect on the salivary secretion and on the blood pressure.

5. Inject 10 or 15 milligrammes of atropine. Note the entire cessation of the salivary secretion, atropine acting as an antagonist to pilocarpine.

6. Stimulate the chorda tympani again. No effect is produced, atropine having paralysed the secretory fibres.

7. Stimulate the sympathetic again. A small effect may be produced, owing to these fibres being more resistant to the action of atropine than those of the chorda tympani.

Pancreatic Secretion. *Demonstration.*—A dog is anæsthetised with morphia and A.C.E. mixture. Put a cannula in one jugular vein for injection, and insert a cannula into the carotid artery for subsequent connection with a mercurial manometer. Open the abdomen by an incision in the middle line, extending from the ensiform cartilage to the umbilicus. The intestines being exposed, find the spot at which the upper part of the jejunum passes back to be attached to the posterior wall of the abdominal cavity, where it becomes continuous with the duodenum. Pass a double ligature round the jejunum at this point. Draw out about two feet of the gut extending downwards from the ligature. Tie it at its lower end, and tie all the vessels connecting the separated bit with the body. Now cut out the ligatured portion of the gut, wash it through under the tap, open it and scrape off the mucous membrane. The mucous membrane is then ground up with sand to a paste, a few drops of 0·4 per cent. hydrochloric acid being added to the sand. Now add to the paste about 200cc.s of 0·4 per cent. hydrochloric acid. Transfer the mixture to an open basin, and raise to boiling point over a flame. When the fluid is actively boiling, add a solution of caustic soda, drop by drop, until the mixture is almost neutral, care being taken to end with the fluid just on the acid side. All the proteins will be coagulated, and on taking the flame away the coagulum will sink to the bottom, leaving the supernatant fluid clear. Filter the fluid off through a plaited filter. In this way a solution of *secretin* is obtained. Now place a fine cannula in the main pancreatic duct. To do this draw the duodenum out of the abdominal wound. The duodenum will be found lying towards the back of the abdomen on the right side, and will be at once recognised by the presence of the pancreas in its mesentery. In the dog the pancreatic duct will be found passing into the duodenum, about half an inch above the point where the lower border of the pancreas leaves the duodenum. The duct is often obscured by one or two small vessels, which must then be double ligatured and cut in order to expose the duct. A ligature being placed loosely round the duct, the latter is opened as close as possible to the duodenum, a cannula inserted and tied in. The cannula is connected by rubber tube with a narrow glass tube which is carried over the edge of the table, so that the fluid coming from it may drop on to a drop recorder, the excursions of which are transmitted by air to a tambour writing on a blackened surface, immediately above the mercurial manometer which records the blood pressure (see Fig. 22). It is advisable to fill this tube with water at the beginning of the experiment. In most cases no spontaneous secretion will be obtained from the pancreas, if the experiment be made on the dog or cat; in the rabbit there is as a rule a slow secretion. Inject into the jugular vein 5 cc.s of the extract made from the mucous membrane. The injection is generally followed almost immediately by a fall of blood pressure, due to the presence of depressor substances in the extract. After a latent period of about sixty seconds, a secretion of pancreatic juice will begin, and will last for five to ten minutes. By repeating the injection the secretion of pancreatic juice may be kept up for many hours. Collect the juice, and show its action on starch, on fat, and on protein. Note

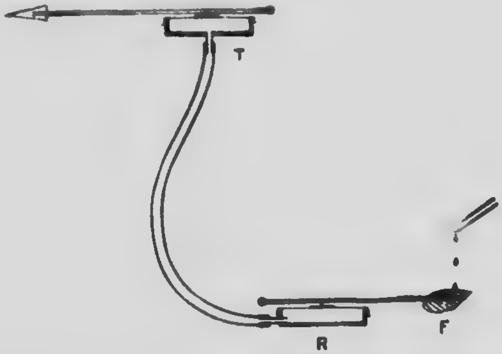


Fig. 22.—Drop recorder. F, goose feather; R, receiving tambour; T, recording tambour.

that it has practically no action on proteins, *e.g.* fibrin, unless it is mixed with succus entericus, or with some unboiled extract of intestinal mucous membrane (containing the ferment enterokinase).

In the same animal a cannula may be inserted in the bile duct, the cystic duct being ligatured to prevent any confusion between the bile secreted by the liver, and that which merely expelled by the gall bladder. Note that in contradistinction to the pancreatic juice, the secretion of bile is continuous. Inject 5cc.s secretin, and note that the secretion of bile is increased twofold.

Production of Jaundice. Bile is secreted under very low pressure. Any obstruction to its flow causes it to pass into the lymphatics of the liver, and thence into the general circulation, by which it is carried to all parts of the body, producing jaundice of the tissues, and the presence of bile salts and pigment in the urine. The ease with which this back absorption takes place can be shown by connecting a burette, containing a solution of indigo carmine, with the cannula in the bile duct. Under the pressure of the fluid in the burette, the indigo carmine passes back into the bile duct and into the lymphatics of the liver, whence it is carried all over the body. This is proved by the blueing of the gums and mucous membranes which is evident shortly after the colouring matter has been allowed to flow into the bile duct. If the animal be now killed the lymphatics of the liver will be found filled with blue fluid, showing the path that has been taken by the latter in its absorption.

LESSON XVII

CONTRACTION OF [illegible] MUSCLE.—CILIARY MOVEMENT.—MOVEMENTS [illegible] STOMACH, INTESTINES.

Contraction of Smooth Muscle.—Set up the crank myograph, as in [illegible] lever a piece of the lower portion [illegible], as recommended by Waller. Take a record on a slowly revolving drum, stimulating the muscle directly with single induction shocks. Compare the resulting record with that of a [illegible] muscle twitch. Stimulate several times at regular intervals, and note staircase effect. Stimulate immediately after the commencement of relaxation and observe the summation.

Ciliary movement.—Pith a frog and divide the lower jaw in the middle line carrying the incision backwards through the pharynx and œsophagus. Place the frog on its back, and fasten back the flaps with pins. Moisten the surface with normal saline. Place a small piece of cork on the anterior part of the palate, and observe how it travels slowly towards the commencement of the œsophagus.

Observe the time taken to travel 5 mm. Apply warm salt solution and observe the acceleration produced.

To see the ciliary motion directly, examine shreds of the mucous membrane from the palate under the microscope in normal saline.

The large cilia on the gills of the mussel or oyster are very well adapted to show ciliary movement. If an oyster be kept lying with the concave shell downwards, it will remain alive for a long time. Snip off small pieces of the gills and tease them gently in some of the fluid from the oyster's own shell, cover and examine with low and high powers.

Movements of the Œsophagus.—The time relations of the movements of the œsophagus can be studied by listening through a stethoscope to the sounds produced by swallowing. Two or three observers can listen with the stethoscope at different points, while one student swallows. When a mouthful of water is swallowed, two sounds are produced. The first sound is sharp and short; and is heard most loudly when the stethoscope is placed under the chin. It is less loud in the front of the neck, and can be heard with diminished intensity over the spine from the upper cervical to the lumbar region. It is probably due to the impact of the fluid against the posterior pharyngeal wall, brought about by the sudden contraction of the mylo-hyoid muscle, and marks therefore the beginning of the act of deglutition.

The second sound is heard best in the epigastrium, or along the left costal margin. When the person observed swallows in the upright position, the sound, which is of a trickling character, lasts between two and three seconds. It begins from four to ten seconds after the first sound, this being the time required for the passage of the wave of contraction down the œsophagus If the observed person is lying on his back, the single trickle is replaced by a series of sounds which are loud and may be described as squirts.

Movements of the Stomach.—These may be observed in a cat which has been fed on bread and milk containing bismuth subnitrate, by means of the Röntgen rays. They are also, however, well shown on the intact rabbit. The rabbit receives a large meal of green food, so as to distend the stomach. On placing it on its back in a trough, it will generally lie perfectly quiet. It should not be tied down nor anæsthetised. On observing the surface of the abdomen after, if necessary, cutting the hairs or moistening them so that they may lie flat on the skin, the successive waves of contraction travelling from about the middle of the stomach towards the pylorus are perfectly evident.

Movements of the Intestines. *Demonstration.* — The movements of the intestines, and their innervation, can be shown on an anæsthetised animal, preferably a dog. The animal having been anæsthetised, both splanchnic nerves are divided, and one of them is placed on electrodes; both vagi are placed on ligatures, but left intact. The body of the animal is then immersed in a tank filled with warm normal salt solution. Note the character of the movements of the intestines. The writhing of the intestines is due to the rhythmic contractions affecting both coats, causing alteration in the lumen as well as varying curvatures of different coils. Make a small opening in the intestine at any point and insert a metal tube, over the end of which a rubber balloon is tied. The rubber balloon is distended with air under pressure, and is connected through a manometer, or through two bulbs containing water for the maintenance of the pressure, with a piston recorder.

(*a*) Record the rhythmic contractions of the gut which recur about twelve times a minute.

(*b*) Pinch the intestine just below the balloon. Note the augmentation of the contractions, which may amount to a long continued contraction of the intestinal wall, immediately surrounding the balloon.

(*c*) Pinch the intestine a few inches above the balloon. Note the immediate inhibition of contractions, and relaxation of the intestinal wall.

(*d*) Stimulate the splanchnic nerve. The contractions are inhibited.

(*e*) Cut and stimulate one of the vagus nerves. There may be an instant inhibition of the contractions, followed by an augmentation. Very often this effect is not obtained at the first trial, but becomes gradually more pronounced as the excitation is repeated.

(*f*) Remove the balloon. Open the intestine at two places, and into the upper opening insert a small ball of cotton wool moistened with soft soap. Note the strong contraction immediately above the bolus, which travels gradually down, and finally drives the bolus out at the lower end of the segment of gut.

(*g*) Try to reintroduce the bolus from the lower opening. This will be found to be impossible owing to the strong contraction above the opening excited by the presence of the bolus.

Experiment.—Immerse a piece of small intestine taken from the cat or rabbit, immediately after the animal has been killed, into a basin of Ringer's fluid, which is kept at a temperature of 37°, and through which a current of oxygen is allowed to bubble slowly. After two or three minutes the intestine will be seen in movement. The movements recur regularly, and affect both longitudinal and circular coats

The contractions of the former cause bending of the loops; of the latter, constriction of the lumen. With the fingers pinch gently the middle of the loop. A contraction is observed to begin just above, *i.e.* on the oral side of the point stimulated. This contraction increases in intensity for a few seconds, and then gradually dies away. It may be succeeded by a second or third. In some cases it passes slowly down the gut. Repeat the experiment, and while the contraction is still well marked, pinch the gut at its upper end, *i.e.* two or three inches above the contracted point. The whole of the gut below the point at which the second pinch is applied is seen to relax. (The 'law of the intestines' is that stimulation at any point causes contraction above and inhibition below the stimulated point.)

LESSON XVIII

INNERVATION OF PELVIC VISCERA

For this purpose a cat may be used, anæsthetised with a large dose of urethane. Make an incision three inches long in the middle line of the abdomen immediately over the symphysis pubis. Cut through the symphysis, and with a blunt instrument forcibly separate the two sides of the pelvis. The peritoneum should not be opened. Introduce the left forefinger into the wound, and separate the peritoneum and the bladder from the side of the pelvis, exposing the sacral plexus. At the bottom of the wound a small artery and vein will be seen running from without inwards towards the rectum. Accompanying these vessels is a small nerve often double, the nervus erigens, or pelvic visceral nerve. Separate it from the vessels, tie and cut it as near as possible to its origin from the plexus, and place it on shielded electrodes. Allow the viscera to fall back into position, leaving one end of each electrode projecting from the wound. Open the abdomen by extending the first incision upwards, and, holding the intestines to the right side of the abdomen, expose the inferior mesenteric artery. Lying on this artery close to its origin from the aorta is a ganglion, the inferior mesenteric ganglion, and running downwards from the ganglion in the meso-rectum are two nerves, the hypogastric nerves. Cut these and put them also on electrodes. Stimulate first the pelvic visceral nerve, and, secondly, the hypogastric nerves, and note the effect on the large intestine and on the bladder. Care should be taken to expose the viscera as little as possible during the operative manipulation, and when exposed to keep them warm by means of flannels wrung out of hot saline solution.

The effects may be made more apparent to a large audience, by inserting rubber balloons through the urethra and anus into the bladder and rectum respectively, and registering the movements of the walls of these viscera by connecting the balloons with recording tambours.

RESPIRATION

LESSON XIX

VOLUME OF AIR BREATHED—CHEMICAL CHANGES IN RESPIRATION—ANALYSES OF INSPIRED AND EXPIRED AIR—ALVEOLAR AIR

Volume of Air Breathed.—In normal respiration, in determining the volume of air inspired and expired at each respiration, it is important to prolong the experiment for some time, in order to obtain an average quantity and to lessen variations occasioned by voluntary interference with the automatic process.

Experiments. (*a*) An ordinary face-piece, such as is used for the administration of nitrous oxide, is fitted with a tube, to which is attached the arrangement of valves shown in Fig. 23.

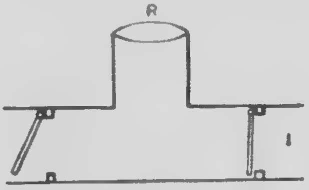


FIG. 23. Chauveau's valves. The student respires through R, the inspired air passes in by I, the expired out by O.

(If the face-piece is not at hand the tube, R, can be held in the mouth, respiration through the nostrils being prevented by clamping the latter with a clip.) O is connected with a gas meter. The person experimented on may be seated comfortably in a chair, and the total volume of air measured that is inspired between the second and third minutes after the beginning of the experiment. The total volume of air passing into the lungs during the minute, divided by the number of respirations per minute, will give the average ventilation of the lungs during normal respiration, the so-called 'tidal air.' Instead of counting the respirations, the respiratory movements may be recorded on a drum by one of the methods described below.

(*b*) The vital capacity, the supplemental air, and the complemental air must next be measured by means of a spirometer. In the first place the subject of the experiment empties his lungs to the utmost into the spirometer, after he has taken the deepest possible inspiration. The supplemental air is measured by breathing into the spirometer at the end of a normal expiration. To measure complemental air the spirometer is first filled with ordinary air, and the subject fills his lungs to the utmost from the spirometer when he has completed a normal inspiration.

Chemical Changes in the Air Breathed.—(*a*) Production of CO_2.

Two bottles containing baryta solution are each fitted with two tubes, one of which dips below the surface of the fluid. The mask and valves already described are fitted to the subject of the experiment, and the two tubes of the face-piece are connected with the bottles in such a way that the inspired air passes in through one bottle, and the expired air out through the other. Barium carbonate is formed in each bottle, but the precipitate is slowly formed and small in amount in the inlet bottle, while in the outlet bottle there is a large and rapid formation, showing the much greater amount of CO_2 in the expired air, produced by oxidation of carbon in the body.

(*b*) Analysis of inspired and expired air.

To analyse inspired air, *i.e.* ordinary atmospheric air, the burette, E (Fig. 24), is first filled with water by means of the tube, G. The pinchcock, D, being closed, G is lowered, and then by opening the cock, E is allowed to fill with air to the mark 100 on the scale. The cock is then closed, care being taken that before closing the cock the fluid in the two tubes, G and E, is on the same level. A specimen of expired air can be obtained in the same way, by connecting the mouth with the top of the tube, and then opening the cock.

The air contained in the burette has now to be analysed by exposing it to the successive action of reagents in Hempel's gas pipettes, which will absorb first the CO_2 and afterwards the O. Before beginning the analysis, the burette should be left to stand for some little time, so that the gas in it may acquire the temperature of the surrounding air, and at this temperature the exact volume of the gas is finally measured at atmospheric pressure, by lowering G so that the levels of the fluid in the two tubes are the same.

The first step is to determine what is present. For this purpose a gas pipette containing strong sodium or potassium hydrate solution is employed.

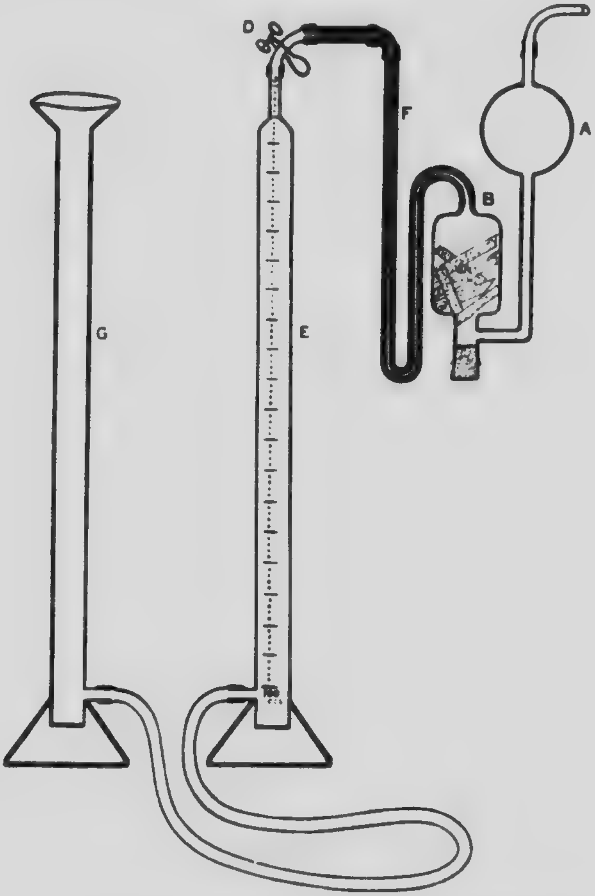


FIG. 24.—Hempel's gas analysis apparatus. Description in text.

A simple form of Hempel's pipette is shown in Fig. 24

These are filled with the absorbent, so that the bulb A remains empty. The apparatus is now arranged as shown in the figure. The open end of the burette is connected with the bulb B of the gas pipette, by means of a capillary tube. To do this, insert the capillary tube, F, in the rubber tube, D (Hempel, p. 55). Slip a piece of rubber tubing, about 2 feet long, over the end of A, and then holding F in the fingers of the right hand and pressing the rubber tube, D, between the thumb and the first two fingers of the left hand, blow through the rubber tube on A, until the liquid in the pipette rises to near the end of the capillary, F. Then insert the end of the capillary in D. If this is properly done, the air enclosed in the capillary should not occupy more than 5 to 10 mm. of its length, and the volume may then be disregarded, since the error arising therefrom is only about 0·03 ccm. If, however, a greater air volume appears in the capillary tube, F should be slipped out of D, and the operation repeated. When the pipette and burette have thus been connected, the pinchcock D is opened, and the levelling tube G is slowly raised. The gas is thus driven over into the pipette. Water is allowed to flow through the capillary, F, until it just reaches the top of the first bulb. The pinchcock at D is then closed. The gas is now enclosed between two volumes of liquid, the absorbent on one side and the water in the capillary on the other. The gas is allowed to stand in contact with the absorbent until the constituent to be removed has been entirely absorbed. The levelling tube is then grasped near the top with the left hand, and brought into a lower position than that occupied by the burette, E. The pinchcock at D is then opened, and the gas is drawn back into the burette, the liquid in the pipette being allowed to rise to exactly the same point at which it originally stood in F. The pinchcock at D is then closed, F is withdrawn from D, and the reading of the remaining gas volume in the burette is made in the manner above described. The loss of volume is equal to the amount of CO_2 contained in the mixture.

To determine the O, another Hempel's pipette is made use of, containing sticks of yellow phosphorus immersed in water. This is connected with the burette as before, and the gas driven over into the pipette. After standing 10 minutes the gas is returned to the burette, and once more measured. The unabsorbed gas consists of nitrogen.

Composition of Alveolar Air.—A sample of alveolar air may be obtained roughly by connecting the gas burette with a

T-tube, one end of which is held in the mouth. The burette being filled with water and its upper end clamped, the observer breathes quietly through the free end of the T-tube. At the end of a normal expiration, he then clamps the other end of the tube, while his colleague lowers the reservoir A and releases the clamp of the burette. He then continues to empty his lungs into the burette until he has obtained 100cc. of gas. The burette is then clamped, left for a time, and the volume accurately measured at atmospheric pressure. The analysis of the gas is then carried out in the same way as that of normal expired air.

LESSON XX

TOTAL RESPIRATORY EXCHANGE—EFFECT OF EXERCISE—RESPIRATORY EXCHANGE IN A SMALL MAMMAL—EFFECT OF TEMPERATURE—PULSE-RESPIRATION RATIO

Total Respiratory Exchange.—The total output of CO_2 during a short period of time may be determined by the arrangement shown in Fig. 25.

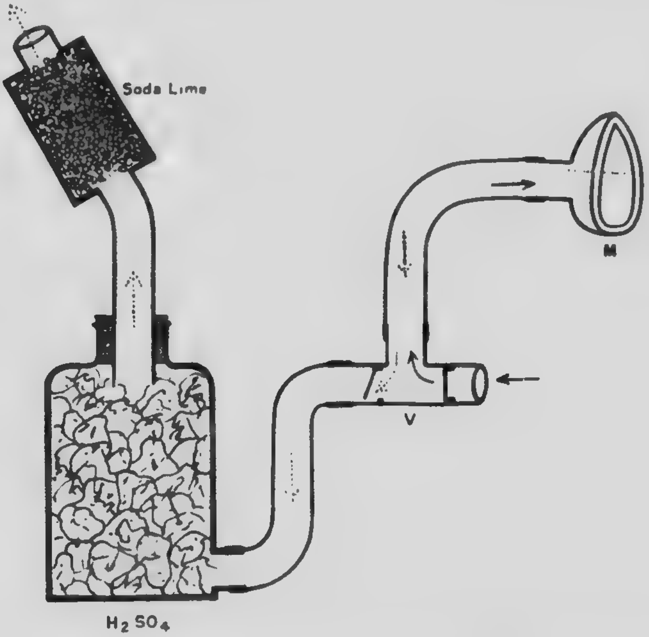


FIG. 25. Apparatus to record total CO_2 output in man for short periods. M, mask; V, Chauveau valve.

The student X, who submits himself to observation, has fitted as closely as possible to his face a face-piece fitted with valves. The outlet tubing is connected first with a vessel packed with pumice-stone saturated with sulphuric acid, and from this a tube passes to a small tin canister packed with soda-lime. At the beginning of the experiment the canister of soda-lime is carefully weighed. It is then connected to the sulphuric acid bottle, and this in its turn to the outlet tube of the respiration face-piece, so that for the space of two minutes (which must be accurately measured), the whole of the expired air of X passes over the sulphuric acid, and through the soda-lime. The soda-lime vessel is then disconnected and re-weighed. The difference between the first and second weights gives the total weight of CO_2 given off by X during the period of observation. The small amount of CO_2 contained in the inspired air may be neglected in an observation such as this, extending only for a short period of time. Having determined the total CO_2 output of X during two minutes while sitting in a chair, let

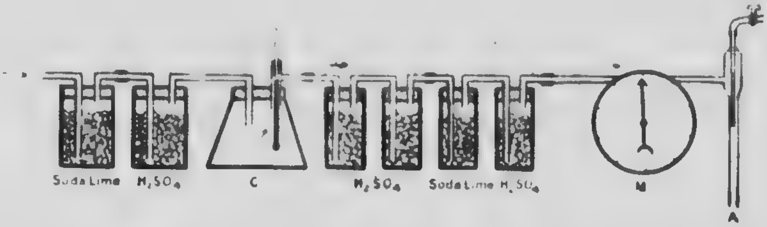


FIG. 26. Haldane-Pembrey respiration apparatus. The animal is placed in the chamber, C. The meter, M, records the volume of air that has passed through the apparatus.

him now run to the bottom of the building and back again, if necessary more than once, until he is out of breath. Then take a second reading of his CO_2 output during two minutes, in order to determine the changes in the gaseous metabolism of the body which accompanies exercise.

The Total Respiratory Exchanges of a Small Animal. The total intake of O and output of CO_2 may be determined on a small animal, such as a mouse, over long periods of time, by a modification of the method just described for man.

The arrangement of the apparatus, as used by Haldane and Pembrey, is shown in the figure.

The animal is placed in a beaker, C, which is tightly corked, the cork being provided with three openings, one of which contains a thermometer, while the other two are for the entry and exit of air. The air is drawn through this chamber by means of an ordinary water filter pump, A. The amount of air drawn through is measured by allowing it to pass through a small gas meter, M. The air passes into the chamber through two vessels, one containing soda-lime to absorb the CO_2, while the second one contains pumice-stone saturated with sulphuric acid to absorb the moisture of the air. Pure, dry air is thus supplied to the animal. Air ascending from the animal chamber passes first through two absorption tubes containing pumice-stone and sulphuric acid, and then through a similar tube containing soda-lime, finally passing through a third sulphuric acid tube, to absorb any moisture which might be given off from the soda-lime. The animal is first weighed in the beaker with the tubes closed. The absorption tubes are also weighed, in both cases a dummy beaker, or similar pairs of tubes, being placed in the other scale pan so as to avoid errors due to condensation of water on the glass. The tubes are then connected up, and the air is drawn through the chamber for a period of 30 minutes. The amount of water and CO_2 given off in this time is determined by the increase in weight of the pair of sulphuric acid tubes, and of the soda-lime + sulphuric acid tubes respectively. The animal is also weighed in the beaker, and the amount of O absorbed is found by subtracting the loss in weight of the animal from the total loss of CO_2 and water.

By means of this apparatus, determine the total respiratory exchanges of a mouse, first with the beaker immersed in water at about 10°, and secondly with the beaker immersed in water at 25°. It will be found that in the latter case the activity of the animal and the extent of its respiratory exchanges are very largely diminished.

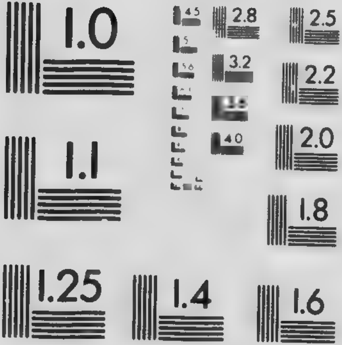
Pulse Respiration Ratio.—Determine in man the number of heart-beats and the number of respirations per minute:—

1. At rest.
2. During exercise.

The ratio of the two figures seen is the pulse-respiration ratio, and should in a man with healthy lungs and heart remain approximately the same, even though the figures may vary considerably

MICROCOPY RESOLUTION TEST CHART

ANSI and ISO TEST CHART No. 2



APPLIED IMAGE Inc

[illegible] East Main Street
Rochester, New York [illegible]
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LESSON XXI

MOVEMENTS IN NORMAL RESPIRATION—EFFECTS OF EXERCISE—ASPHYXIA—OF CO_2—OF O—APNŒA—DEGLUTITION—CHEYNE-STOKES BREATHING

The Regulation of the Respiratory Movements.—(*a*) Normal Respiration.—The extent and rhythm of these movements is best recorded graphically in a man by using a pneumograph, such as that devised by Bert and modified by Haldane. It consists of a brass plate which rests on the lower end of the sternum, and carries a bent copper tube, the ends of which are closed by thick rubber membrane. A broad tape is passed round the chest, and attached at each end by means of hooks to the rubber membrane closing the two ends of the cylinder. From the cylinder a tube passes to a recording tambour. In the course of this tube a T-piece should be inserted, the third end of which can be left open while adjusting the apparatus (Fig. 27).[1] Every expansion of the chest pulls out

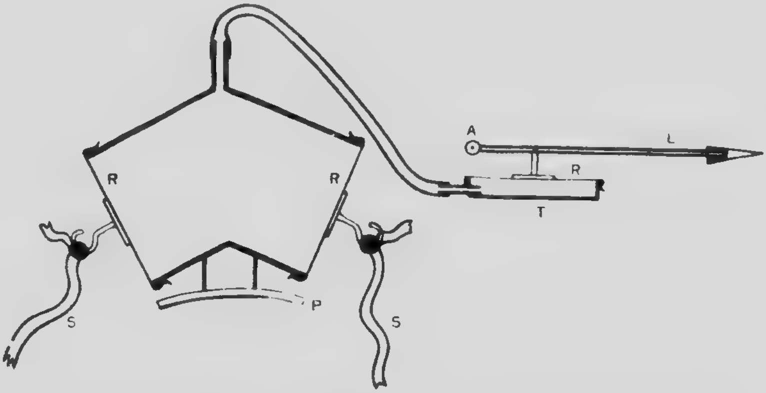

Fig. 27.—Bert Haldane Pneumograph. R, R, R, rubber membranes; P, chest plate; S, strings passing round the chest; T, recording tambour.

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[1] This is not shown in the figure.

the rubber membrane at the two ends of the pneumograph, and therefore sucks in air from the recording tambour. The lever attached to the latter, therefore, makes excursions which are proportional to the extent of the respiratory movements, and can be recorded on a moving blackened surface. By this means take tracings of the respiratory movements of X (*Note.*--The person experimented on is throughout designated as X),

1. While he is sitting in a chair.
2. While standing up.
3. Immediately after he has run downstairs to the bottom of the building and back again.

Notice the great increase in rhythm and amplitude of movements determined by muscular exercise.

(*b*) Effects of asphyxia.

For this purpose X is made to breathe through the mouth into and out of a bag which has been previously filled with air; the nostrils must be clamped. It will be observed that the respiratory movements become first deeper and then quicken in rhythm. The experiment should be stopped as soon as actual discomfort is experienced, which will be when X is in a condition of dyspnœa.

At this point transfer some of the mixture of gases remaining in the bag to a 100 cc. measuring vessel, and determine its composition by the method described on page 71. It will be found that the bag at the end of the experiment contains a mixture of gases, with a large proportion of CO_2 and a considerable diminution in the amount of oxygen. Is the dyspnœa due to the increased CO_2 or to the diminished oxygen?

(*c*) Effect of increase of CO_2.

The effect of increased CO_2 may be recorded by making X breathe through a bag containing 3 to 5 per cent. CO_2 mixed with air. X will experience at once a sense of breathlessness, and the dyspnœa will be evidenced in the graphic record of his respiratory movements. The same effect on the respiratory movements is found if X be made to breathe a mixture containing pure oxygen with the same percentage of CO_2. It is therefore due to the excess of CO_2, and not to lack of oxygen.

(*d*) Effect of diminished oxygen.

This may be studied in two ways.

While the respiratory movements are being recorded, X is made to breathe into and out of a bag, a cylinder containing soda-lime being interposed in the course of the current of air in order to absorb the CO_2 given off at each respiration. A still simpler method is to make X breathe from a bag containing mixtures of air and pure nitrogen, and, therefore, differing from ordinary air only by containing a smaller percentage of O. It will be found that, within considerable limits, the depth and rhythm of respiration is independent of the amount of O present. While breathing a low percentage of O some care is necessary, as in many individuals there may be an actual sudden loss of consciousness before any appreciable feeling of dyspnœa, or even discomfort, has been experienced.

(*c*) Apnœa.

While the respiratory movements are being recorded X inspires and expires as forcibly as possible during a period of forty seconds to one minute. He then ceases his efforts. It will be found that a long pause ensues, during which no respiratory movements take place (apnœa), and the movements then begin slowly and gradually.

Repeat the experiment, but let X breathe in and out of a large bag containing air with 5 per cent. CO_2. It will be observed that in the latter case no cessation of respiratory movements occurs, however energetic the forced movements of respiration be made. It thus seems that the period of apnœa is due chiefly, if not wholly, to the diminished tension of CO_2 in the alveoli, brought about by the forced respiratory movements.

Effect of Deglutition. Place another subject in a chair, and let him breathe quietly, without any attempt at forced respiration. At the end of a quiet inspiration let him hold his breath as long as he conveniently can, while some one else takes the time. Under the circumstances a convenient and fairly definite end point will be reached in about half a minute.

Wait until he has recovered his normal state. Then let him hold his breath again, but as soon as he feels any inconvenience (a little before the end point just noted) let him sip water, and continue sipping till he feels that he has reached the same state as in the first part of the experiment. The time will be about ten to fifteen seconds longer.

Repeat the first part of the experiment again, and see that the time is the same as it was originally.

Cheyne-Stokes Respiration.—As Haldane has recently shown, this can readily be induced in a normal individual.

(*a*) Record the respiratory movements by the pneumograph as before, then let the subject breathe through a tube about 120 cm.s long and 2 cm.s diameter.[1] The record will assume a typical Cheyne-Stokes pattern, which is continued for a little time after the tube is removed.

(*b*) Repeat the experiment, but place a tin canister of about 400 cc.s capacity, containing soda-lime in front of the long tube. In most individuals Cheyne-Stokes respiration is induced as before; and is now beyond cavil due to lack of oxygen, as the carbon dioxide is absorbed by the soda-lime.

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[1] The length of the tube must be proportioned to the individual. If the tube is too long the respirations are merely deepened and remain regular in rhythm. For some persons a tube 130 cm.s × 1·5 cm.s answers well.

LESSON XVII

INFLUENCE OF THE VAGUS ON RESPIRATION—DEMONSTRATION OF HEAD'S METHOD

A rabbit is given a subcutaneous injection of chloral hydrate (1 cc. of a 50 per cent. solution per kilo body weight). When it is anæsthetised it is fixed on the board. An incision, two inches long, is made in the middle line over the ensiform cartilage, opening the abdominal cavity at its anterior part. On turning up the ensiform cartilage, two slips of the diaphragm are seen on its under surface. These slips contract with every contraction of the diaphragm, and are used in Head's method to sample the activity of the whole diaphragm. Threads, each carrying at one end a small flat button of cork, are passed from the abdomen, through the diaphragm and the walls of the thorax, between the fifth and sixth ribs on each side. The two threads are knotted over the front of the sternum, so that a fixed point is thus supplied, from which the diaphragm slips may pull. One blade of a fine pair of scissors is inserted between muscle and cartilage, taking care not to injure the muscle in any way. The cartilage with the insertion of the muscular slips is cut away from the sternum. A hook is fixed into the cartilage and attached, by a thread passing over a pulley, to any ordinary writing lever, which marks on the smoked surface of a drum. (If there is any difficulty in transmitting the movements of the slips by means of pulleys, the thread may be attached to the lever of a Marey's tambour, and the movements transmitted from this to a recording tambour by a rubber tube.) In order to supply a fixed point from which the slips may pull, the cut end of the sternum is clamped to a rigid support. In this way we obtain a tracing of the movements of the slips, which serves as an index of the rhythm and extent of the diaphragmatic movements. Tracheotomy is now performed, and a glass T-tube tied into the trachea. The vagi are also exposed on each side, and fine silk passed round each, taking care not to injure them in any way. The following experiments are then to be performed:—

(*a*) Record the normal movements.

(*b*) Clamp one limb of the T-tube, and connect the other to a balloon containing a mixture of air with 5–20 per cent. of CO_2.

(*c*) Replace this balloon with another containing pure nitrogen. In each case remove the balloon as soon as dyspnœa is produced. Note the alteration in the respiratory movements produced by increased tension of CO_2, or diminished tension of O.

(*d*) Connect a rubber tube to one limb of the T-tube, closing the other limb. With the mouth blow up the lungs. The diaphragm slip at once relaxes, and remains relaxed during the inflation.

(*e*) Suck out air from the lungs. A strong contraction of the slip is at once produced.

(*f*) Repeat the inflation of the lungs at frequent intervals.

During the repeated inflations there is standstill of the diaphragm, and the standstill lasts for some time after the inflation is discontinued (*apnœa*).

This apnœa is due either to summation of impulses from the lungs, or to washing out of CO_2. Repeat experiment, but inflate from a balloon containing 6 per cent. CO_2. During a single inflation standstill of the slip is produced as before. If the inflation be repeated many times, it is not, however, succeeded by a lasting cessation of respiration.

Now cut both vagi. Note the change in type of respiration produced. Repeat the procedures already tried on the intact animal. CO_2 now produces increased depth, but no increased rhythm of respiration. Inflation of the lungs has no effect, showing that the previous standstill during single inflation was dependent on the integrity of the vagi. Pick up the central end of one divided vagus and stimulate it with—

(*a*) Weak induction shocks.

(*b*) Constant current, both ascending and descending.

Note the effects produced in each case. Finally, clamp the trachea, and note the character of the respiratory movements produced in the various stages of asphyxia, until the death of the animal.

Note.—We can, with Miescher, distinguish two kinds of apnœa, viz.:—

(*a*) *Apnœa vagi.*—An inhibition of inspiration produced reflexly by inflation of the lungs, ceasing as soon as the lungs are allowed to collapse.

(*b*) *Apnœa vera.*—Cessation of respiration due to diminution of the CO_2 tension of the blood—and therefore produced by inflation with any neutral gas—and only passing off slowly, as the CO_2 gradually accumulates again in the blood.

Stethoscope and Phonendosco .—The stethoscope is used in two forms, the 'binaural' and the 'stick' stethoscope. Each has a small bell-shaped opening which receives the sound, which in the binaural is transmitted simultaneously to both ears by two rubber tubes, and in the 'stick' form is conveyed by a wooden tube to one ear only, which is applied to the flat ear-piece. The binaural is the more sensitive to faint sounds, and more convenient of application; but the sounds are more liable to disturbance by extraneous noises. The wooden instrument is nearly free from this defect, and moreover conveys the cardiac impulse as well as the sounds to the observer, so that both can be noted at once. The phonendoscope is a more elaborate and sensitive form of instrument. It consists of a large flat tambour with two elastic diaphragms (discs), the inner one being the more sensitive. The outer one can be removed if required. It is provided with a detachable rod which is used when it is required to auscultate small definite areas, *e.g.* the heart valves, and arteries. The rod is then applied with carefully graduated pressure over the parts to be examined.

Rubber tubes with ear-pieces convey the sounds, magnified by the diaphragms of the transmitter, to the ears of the observer.

Heart sounds.—Using either instrument, listen ('auscultate') over the 'apex beat,' for the first sound; now listen over the second right and second left costal cartilages, for the second aortic and pulmonary sounds. Note the differences in character in the different places. Note effect on heart of (α) holding the breath, (β) swallowing, (γ) inspiration and expiration.

Breath sounds.—Using either instrument, listen carefully over the right side of the thorax in the region of the nipple.

Observe the faint rustling sound audible during inspiration and the beginning of expiration, the 'respiratory susurrus.' The origin of the sound is debated. The greater part of expiration is silent.

Next listen over the trachea at the root of the neck; a much shriller, whistling sound is heard, caused by the air passing through the rima glottidis, both on inspiration and expiration. This is called 'bronchial breathing,' and is normally heard only over the larger air passages. It can best be heard over the region of the fourth dorsal spine behind, this being the position in the thorax where the bronchi lie nearest to the surface, and closely corresponds to the bifurcation of the trachea.

The Laryngoscope.—With this instrument the movements of the vocal cords during phonation can be studied.

It consists of two parts: (*a*) A large concave mirror, attached by a strap and universal joint to the observer's forehead, having a central hole through which the eye of the observer looks down into the larynx by means of (*b*) a small concave mirror set obliquely on a long handle.

Sometimes a small electric lamp with a condensing lens is used instead of (*a*).

In using the instrument, a lamp is placed behind and to one side of the subject's head. The large mirror is adjusted to throw a converging beam of light on the uvula. The small mirror is warmed and moistened by dipping it in water at 40°, and then is placed gently upon the uvula. If the latter is very sensitive, it may be first painted with a 5 per cent. solution of cocaine hydrochloride, which prevents reflex stimulation of the vomiting centre. The light from the large mirror will be reflected from the small one through the rima glottidis, and will brilliantly illuminate the interior of the larynx, which can thus be seen by the observer's eye, reflected in and magnified by the small concave mirror, near the principal focus of which the vocal cords, &c., will be situated.

As the image is reflected, the anterior part will be seen posteriorly and *vice versa*.

THE BLOOD

LESSON XXIII

COUNTING OF CORPUSCLES—ESTIMATION OF HÆMOGLOBIN

Counting of Red Corpuscles: Thoma-Zeiss Hæmocytometer.

This consists essentially of two parts, the diluting pipette, and the counting chamber. The pipette has a long narrow stem which holds one part, and a bulbous end holding 100 times the volume of the stem. The counting chamber is a slide on which is cemented a circular table of glass; the top of this table is ruled with lines $\frac{1}{20}$ mm. apart; these crossing at right angles form a series of squares each $\frac{1}{400}$ sq. mm. in extent. Outside the circular table is cemented a square plate, which is $\frac{1}{10}$ mm. higher than the table in the centre. When a thick cover glass is placed so that its edges rest on this part, each square has then a roof $\frac{1}{10}$ mm. distant, the cubic capacity of the space over each square being therefore $\frac{1}{20} \times \frac{1}{20} \times \frac{1}{10} = \frac{1}{4000}$ cubic mm.

Experiment.—Suck up blood from a large finger prick[1] up to the mark 1 on the pipette, wipe the end, and rapidly suck up Hayem's Fluid ($HgCl_2$ 0·5 gram.; Na_2SO_4 0·5g.; $NaCl$ 1g.; H_2O, 200 ccs.) to the mark 101, and turn the pipette about, so that the blood and the fluid can be thoroughly mixed by the little bead in the hollow part of the pipette. The blood is thus diluted 100 times, since in the hollow part of the pipette there is present 1 part of blood and 99 parts of Hayem's solution, 1 part of Hayem's solution remaining unmixed in the stem of the pipette. Blow out a few drops, so as to expel this fluid, and then touch the centre plate with a small drop of the mixed blood. Apply the cover glass. The blood should pass over the top of the centre table, and should not extend to the supporting sides. Next count the corpuscles in at least 30 squares, using ⅙-inch objective, and a high power eye-piece. It will be noticed in so doing, that some corpuscles lie exactly on the dividing lines. Consider that only the corpuscles lying on the left hand and bottom lines belong to the square, those on the remaining two being counted with the other squares. Every fifth square is intersected by a median line, supposed to facilitate counting of large numbers.

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[1] The finger must be pricked so that the blood runs freely, without compressing or ligaturing the finger, which causes an excessive exudation of lymph, and a corresponding deficiency of corpuscles.

Take the mean of 30 squares, multiply the result by 100 (to allow for the dilution), then by 4000, to obtain the number per cubic mm.

White Corpuscles.

The estimation is carried out in an exactly similar manner, except that a pipette giving a dilution of 1 in 10 is used, and a diluting fluid consisting of– distilled water 100 ccs., glacial acetic acid 3 ccs., 1 per cent. aqueous gentian violet 1 cc. This fluid dissolves the red corpuscles, and makes the white corpuscles more evident.

The mean of at least 100 squares should be taken, or the large squares used, formed by the extra lines mentioned above.

Estimation of Hæmoglobin : Gowers-Haldane Hæmoglobinometer.—The apparatus consists of the following:—

(*a*) A pipette by which exactly 20 cub. mm. of blood can be measured.

(*b*) A cylindrical glass vessel graduated from 10 up to 150. This when filled with fluid up to the mark 100 contains exactly 2 ccs.

(*c*) A glass vessel the same size as (*b*) containing a 1 per cent. solution of ox blood, which has been saturated with CO gas. The oxyhæmoglobin has thus been completely transformed into carboxyhæmoglobin.

(*d*) A stand in which the two tubes (*b*) and (*c*) can be placed side by side.

(*e*) A drop bottle containing distilled water.

(*f*) A very narrow pipette, with an attachment to fit on to a gas tap.

(*g*) A lancet or needle to obtain a drop of blood.

Experiment.—Obtain a drop of blood from the finger in the same manner, and with the same precautions, as described under the Hæmocytometer. The pipette is filled with blood up to the mark 20 cmm. A convenient method is to fill the pipette to slightly above the mark, then carefully wipe the point, when the level of the blood can be lowered accurately by drawing the end of the finger slowly across the end of the pipette. The graduated tube having been previously filled with distilled water up to the mark 20, the contents of the pipette are blown out into it, and the pipette is washed out with a little more distilled water, which is added to the tube. The narrow pipette attached to the gas tap is now inserted into the tube, but must not be passed below the surface of the fluid, and coal gas (which contains a large percentage of CO) is passed, until the tube is full. The pipette is withdrawn while the gas is still flowing, and the mouth of the graduated tube instantly closed with the finger. The tube is then tilted up and down ten times—it must not be shaken, or the contents will froth. The graduated tube is then compared with the standard, and distilled water added drop by drop, mixing after each addition, and scraping any adhering fluid from the end of the finger with the edge of the tube, until there just ceases to be any observable difference between the tints of the two tubes, when examined close together against a white background, changing them to and fro while doing so. This point is then noted, and the dilution proceeded with, until a difference of tint just reappears. This point is noted, and the mean taken between it, and the point where a difference just ceased to be visible. This mean point on the scale reads directly the percentage of the normal amount of hæmoglobin present in the sample tested. This should reach 100 on the scale: that is, the 20 cmm. of blood are diluted up to 2 ccs., *i.e.* 100 times, when the tint appears the same as that of the standard 1 per cent. solution of blood (carboxy-hæmoglobin).

LESSON XXIV

THE GASES OF THE BLOOD

Two methods are available for the analysis of the gases of the blood. In the first the blood is exposed to a vacuum, and the gases given off are estimated in a narrow tube; in the second the blood is treated, first with potassium ferricyanide, by which the oxygen is liberated, and then with tartaric acid, thus giving off the CO_2, and the increase in pressure caused by the liberation of each gas is measured in a manometer.

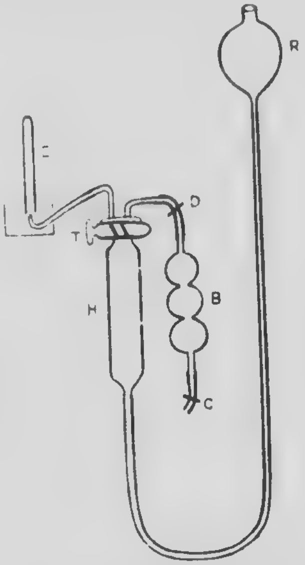

Fig. 28.—Leonard Hill's pump. R, movable vessel; H, fixed vessel; T, three-way tap; B, vessel for blood; E, eudiometer; C, D, screw clips on rubber ends of B.

Leonard Hill's Pump.—This consists of two bulbs containing mercury, and connected by pressure tubing. The one bulb is open at the top (R, Fig. 28) and can be moved up and down. The other bulb, H, is fixed, and closed above by a three-way tap, which connects the bulb either with the blood chamber, B, or the eudiometer tube, E.

Experiment.—The air is first removed from the blood chamber, B. To do this, place B vertically, raise the bulb, R, and turn the tap, T, so as to fill the chamber, B, with mercury. Close the rubber tube, C, at the top of B, by a screw clip, and lower the bulb, R, so that a vacuum is produced in B. Repeat this three or four times, at the last time 2 or 3 ccs. of mercury should be left behind in the exhausted bulb. Close up the clamp at the other end of B, and remove and weigh the chamber.

Connect the rubber tube, C, with the cannula in the artery or vein, taking care that no air remains in C. Open the screw clip and let from 8 to 10 ccs. of blood flow into B. Close the clip and weigh the chamber, the difference between this and the first weight is the amount of blood that has been taken. Defibrinate the blood by shaking it with the mercury left behind in the bulb. Replace B on the pump, hanging downwards as at first. Exhaust the bulb, H, and then relax the screw clip, D. The blood gases pass on into H. The tap is then turned and the gases sent on to the eudiometer E, where they displace the mercury with which the eudiometer was filled. Repeat this process until all the gases have been given off, placing B in warm water to assist the process. Water will condense in it; this must not be allowed to pass on with the blood gases into E. Finally transfer the eudiometer tube to a vessel of mercury, see that the levels of mercury inside and outside are the same, and read off the volume of gas. Take also the temperature (if greater accuracy is required, the eudiometer tube can be surrounded by a water jacket to keep the temperature constant), and the barometric pressure. The volume of the mixed gases at 0° and 760 m. is given by the equation

$$V = \frac{V^1}{1 + t \times 0{\cdot}00367} \times \frac{H - f}{760}$$

Where H = the barometric pressure
t = the temperature
f = the tension of aqueous vapour (See Septon's Tables).

Introduce by means of a bent pipette 20 per cent. potassium hydrate solution into the eudiometer. This absorbs the CO_2. Measure the diminution of volume, then introduce 10 per cent. pyrogallol solution, and measure the volume of O absorbed. The remainder is supposed to be nitrogen.

Barcroft and Haldane's method.[1]—The apparatus consists of a small glass vessel of known capacity, which has a hollow stopper, from which pressure tubing leads to a manometer. To the stopper is attached a little shelf, which will hold about 0·3 ccs. of liquid, which can be easily tipped out into the vessel, when this is inclined (see Fig. 29). The manometer is of glass, 2–2·5 mm. in bore, and has a flexible rubber part at the bottom of the U, so that the level can be easily adjusted by means of a screw clamp. The free side is graduated in millimetres, the other in $\frac{1}{100}$ths of a cubic centimetre. This manometer is filled with water coloured with methylene blue. The whole apparatus is in duplicate, so that a control experiment can be carried out under identical conditions.

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[1] See Barcroft and Haldane, *Journal of Physiology*, xxviii. p. 232, and Barcroft, *Journal of Physiology*, xxix. p. 181.

Experiment.—Take two of the glass vessels and into each place 1·5 ccs. of 0·5 per cent. ammonia solution.[1] Into each little shelf place 0·25 cc. of a saturated solution of potassium ferricyanide. Take a hypodermic syringe, preferably of special construction, and introduce into it a drop or two of 1 per cent. solution of hirudin, or failing this 0·1 cc. of 2 per cent. ammonium oxalate solution. Draw out 1 cc. of blood from the artery or vein into the syringe, and carefully expel it into one of the vessels, below the ammonia. Into the other control vessel place in a similar manner 1 cc. of freshly distilled water.

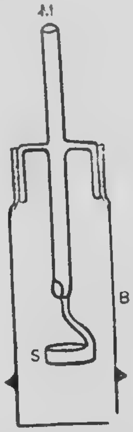

Fig. 29. Barcroft-Haldane vessel. M, tube through stopper, open at both ends; S, shelf to hold potassium ferricyanide or tartaric acid solutions.

Place both vessels in the same water bath, and, when the temperature is even, close the taps of the gauges, first adjusting them so that the level stands at zero. Take out each vessel in turn, shake carefully so as to lake the blood, tip out the ferricyanide solution, and replace both bottles in the water bath. When the temperature is again even, re-adjust the levels in the *closed* ends of the two gauges, so that they stand at the zero mark (that is, bring the apparatus back to the volume it had at first). Read off the level in millimetres in the *open* ends (that is, the difference in pressure caused by the evolution of O from the blood); if the control manometer also shows a rise, subtract this reading from the reading of the blood. Read also the temperature of the water bath.

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[1] NH_4OH, sp. gr., 0·880, 0·5 ccs. Distilled water 99·5 ccs.

As the normal barometer pressure of 760 mm. Hg is equal at 15° to a column of water 10,340 mm., the volume of oxygen given off at this pressure is equal to the volume of air in the blood gas tube and its connections, multiplied by the corrected reading of the gauge in millimetres, and divided by 10,340.

Thus, if the total capacity of the apparatus is 23·35 ccs. and that of the fluids put in is 2·75 ccs., the volume of air is 20·6 ccs. If now the reading of the gauge = 100·00 mm. the oxygen given off will be $20{\cdot}6 \times \frac{100}{10{,}340}$ ccs. = 0·199 ccs. If the temperature were 14° this would correspond to 0·189 cc. of O at 0°. If this came from 1 cc. of blood the combined oxygen would be 18·9 per cent.

Remove the stopper, place on the shelf 0·25 cc. 20 per cent. solution of tartaric acid, and proceed as before. The CO_2 given off is measured in a similar manner to the O, except that the volume of the liquid is not subtracted from the volume of the vessel, as at room temperature the blood mixture absorbs approximately its own volume of CO_2.

PHYSIOLOGY OF THE SECRETION OF URINE

LESSON XXV

SECRETION OF URINE. DEMONSTRATION.

For this experiment either a dog, cat, or rabbit may be used. The animal being anæsthetised, the trachea is exposed and a thread passed round it, so that tracheotomy may be performed later on. Put a cannula in the carotid artery on one side, and tie and cut one vagus nerve, so that its peripheral end may be stimulated. Insert a cannula previously filled with salt solution into one jugular vein. If a rabbit be used, expose the bladder and tie into it a cannula, so that the urine may flow away and be collected in measuring cylinders. In the case of the dog it is better to insert cannulæ into both ureters. To expose the ureters make an incision parallel to Poupart's ligament, about one inch to its inner side and continue the outer end of the incision vertically upwards for two inches. Cut through the aponeurosis of the external oblique muscle, and then divide carefully the fibres of the transversalis about half an inch from the hinder insertion of the muscle. Then cut through the layer of fascia on to the subperitoneal fat, just beyond the line where the anterior layer of peritoneum is reflected on to the posterior abdominal wall. It is a little difficult in thin animals to avoid opening the peritoneal cavity. With the two forefingers strip back the peritoneum so as to expose the iliac vessels. The ureter will be seen crossing these vessels on its way to the pelvis. Tie a ligature round the ureter, open it, and insert and tie in a cannula, on the kidney side of the ligature. If it is not desired to estimate the secretion of the two kidneys separately, the two cannulæ may be joined by a Y-tube and the urine collected in graduated cylinders. Now connect the arterial cannula with a mercurial manometer, and record the blood pressure on a kymograph.

1. Measure the normal secretion during a period of ten minutes.

2. Inject into the jugular vein 20 grammes of glucose dissolved in 20 ccs. water, and measure the subsequent flow during two periods of ten minutes each.

3. Stimulate the peripheral end of the vagus repeatedly, so as to lower the blood pressure. Note the diminution in secretion thereby produced.

4. Inject slowly into the jugular vein 5 ccs. of a saturated solution of indigo carmine, and note how soon the colour appears in the urine.

5. Insert a tracheal cannula and carry on artificial respiration. Divide the spinal cord through the atlanto-occipital membrane, *i.e.* at the lower border of the medulla. Note the effect thereby produced on the arterial blood pressure, and on the flow of urine.

LESSON XXVI

INFLUENCE OF LOCAL VASCULAR CHANGES ON THE SECRETION OF URINE. DEMONSTRATION.

To study this it is necessary to record the changes in the volume of the kidney. Cannulæ are first placed in the carotid artery, the jugular vein, and in the two ureters or the bladder, as described in the previous experiment. The animal is then inclined, so as to lie somewhat on its left side. In the case of the dog, an incision four inches long is made, running obliquely downwards and forwards, parallel with and one inch below the last rib on the right side. The tense fascia covering the erector spinæ is thus exposed at the back part of the wound. Incise this freely upwards and downwards. The erector spinæ muscle is then retracted, and an incision made through the deep layer of the fascia, immediately outside the tips of the transverse processes of the vertebræ, so as to open the abdomen behind the peritoneum. The opening thus made may be somewhat enlarged by incising the abdominal muscles. The lower end of the kidney is then exposed. Insert the forefinger into the wound, and hook out the kidney, so that it lies outside the abdominal cavity, attached to the animal by a pedicle composed of the renal vessels and ureter. Take care that the edge of the opening into the abdomen does not press upon the pedicle. Strip off the capsule of the kidney so as to free it from all attachments except the vessels, and insert it into an oncometer, which has been previously warmed to body temperature. Schäfer's air plethysmograph is the most convenient for this purpose. It consists of an oblong box, which may be shaped roughly to the kidney. In one edge is a depression in which the renal pedicle lies. The box may be made either of vulcanite, or of Stent's composition, which can be easily moulded, after heating in hot water, into any desired shape. The kidney having been arranged in the box, the latter is covered with a glass plate, the oncometer being made air-tight by thickly coating the plate and edges of the box with vaseline, and by packing wisps of cotton wool soaked in vaseline round the renal vessels, as they pass over the groove in the edge of the box. A glass tube which is inserted into the box, is connected by india-rubber tube with a piston recorder, or some other form of volume recorder. The lever of the latter is arranged to write on a blackened surface. The box is then clamped in position, so that the kidney lies naturally without any torsion of, or tension on, its pedicle, and the whole apparatus is covered with cotton wool to prevent loss of heat. If these arrangements have been properly carried out, any changes in the volume of the kidney cause a corresponding alteration in the lever of the piston recorder. This should show waves corresponding to the cardiac and respiratory undulations on the arterial blood pressure. Now record the volume of the kidney, the general blood pressure, and the renal secretion under the following conditions:

1. Normal, during a period of ten minutes.

2. Excite the peripheral end of the vagus. Note the diminution in blood pressure, in the volume of the kidney, and in the urine.

3. If a rabbit is used, inject a dose of caffeine (about 15 milligrammes per kilo). Note the effect on the blood pressure, the volume of the kidney, and the urine. The two latter may be affected without the former.

4. When the effect of the caffeine has passed away, inject 10-20 gms. of glucose.

5. Inject adrenalin and note the effect on the general blood pressure, the volume of the kidney, and the urine.

TEMPERATURE

LESSON XXVII

TEMPERATURE OF MAN — DAILY AVERAGE — EFFECT OF EXERCISE—EXPOSURE TO COLD — HEAT PRODUCTION IN MUSCLES OF FROG AND MAMMAL. DEMONSTRATION.

Temperature of Man.—This is best taken by means of the usual clinical thermometer. Before commencing the experiments, compare the thermometer to be used with the standard, as the ordinary commercial type usually reads too high.

The temperature can be taken in (*a*) the mouth; (*b*) the closed axilla; (*c*) the rectum; (*d*) the stream of urine. The last method is the one least liable to accidental error, the first the most so.

Experiments.—The student is to perform the experiments noted below on himself, as occasion serves, and record the results on a chart.

1. Take the temperature at each hour of the day, and observe the normal daily variation.

2. Take the temperature before and after severe muscular exercise. The methods (*c*) and (*d*) will give the most accurate results in that case, the method (*a*) is usually unsatisfactory, especially in cold weather, as the tissues of the mouth become cooler than the rest of the body.

3. Take the temperature before and after a cold bath.

Heat Production during Muscular Contraction. *Demonstration.*—Take two thermo-electric needles, made of constantine and iron, and set up a circuit with these, a compensator, and a sensitive low-resistance galvanometer. The galvanometer and various junctions should be protected from accidental variations of temperature by cotton wool. The apparatus should indicate a difference of temperature of $\frac{1}{10}$th to $\frac{1}{20}$th of a degree centigrade between the two needles. Note the direction of the movement of the galvanometer spot when one needle is heated.

Pith a frog, and expose both sciatics and gastrocnemii. Insert a needle longitudinally into each muscle, and wait till the galvanometer spot is steady. Excite the sciatic of one side with tetanising shocks for from half to one minute; the galvanometer spot should move in the direction that indicates greater heating of the needle embedded in the excited muscle. Repeat on the other side.

The same experiment can be performed on a recently killed cat. The muscles remain in good order for about half an hour after the circulation has stopped, and the technique is rather less difficult than with the frog.

NERVOUS SYSTEM

LESSON XXVIII

PFLÜGER'S LAW—ELECTROTONIC ALTERATION IN EXCITABILITY—ELECTROTONIC CURRENTS.

Pflüger's Law.—Prepare two non-polarisable electrodes, and connect them with a rheochord, commutator, Morse key, and one or two cells, so as to give any desired strength of current through the electrodes in either direction. Make carefully a gastrocnemius-sciatic preparation, and lay the nerve across the electrodes in the moist chamber. Trace the direction of the current flowing through the nerve; it passes either in an *ascending* direction, away from the muscle, or in a *descending* direction, towards the muscle. Mark the commutator accordingly.

(*a*) Arrange the rheochord and commutator so as to give a weak ascending current through the nerve. Depress the Morse key and 'make' the current; after two or three seconds let the key up and 'break' the current.

Note the result—in this case a contraction of the muscle occurs at 'make,' and nothing apparent happens at 'break.'

(*b*) Repeat with a weak descending current.

Shift the rheochord contact, so as to give 'medium' current, and note the effects of

(*c*) Medium ascending current, make.

(*d*) Medium ascending current, break.

Reverse the commutator and note the effects of

(*e*) Medium descending current, make.

(*f*) Medium descending current, break.

Remove the rheochord, and take the current directly from one or two cells. Perform the same series of four experiments.

(*g*) Strong ascending current, make.

(*h*) Strong ascending current, break.

(*j*) Strong descending current, make.

(*k*) Strong descending current, break.

The results should be according to the table, where C indicates a contraction, and O no visible effect.

Current strength	Ascending		Descending	
	Make	Break	Make	Break
Weak	C	O	C	O
Medium	C	C	C	C
Strong	O	C	C	O

Success in the experiment depends on careful attention to detail. The electrodes should not have too great a resistance, and the nerve must be kept moist. The position of the rheochord slides for 'weak' and 'medium' currents must be determined by guess and trial, as it will vary with the resistance of the nerve and electrodes.

Electrotonic Alteration of Excitability.—Make a gastrocnemius-sciatic preparation, and place it in a moist chamber on two pairs of electrodes, the pair nearest the muscle being of the ordinary type and connected with an induction coil, the pair furthest away being non-polarisable, and connected with a rheochord and battery.

(1) Slide the secondary coil to such a distance from the primary that a break shock causes no contraction. Pass a descending current through the non-polarisable electrodes, *i.e.* so that the kathode is next the testing electrodes. Give a break shock—it now causes the muscles to contract.

(2) Re-arrange the secondary coil so as to give a good contraction at break. Reverse the commutator, and pass an ascending current through the nerve; the anode is now next the testing electrodes and the break shock is now ineffective.

(3) Perform the same pairs of experiments with tetanising currents.

Electrotonic Currents. (Demonstration.)—With the circuit shown in Fig. 13, Lesson IV, the electrotonic currents of frog's nerve can be easily demonstrated, a pair of non-polarisable electrodes being placed on the nerve, instead of the stimulating electrodes from the induction coil.

LESSON XXIX

TENDON PHENOMENA—MAN AND RABBIT SPINAL REFLEXES—MAMMAL AND FROG

Tendon Phenomena in Man.—Study this by Waller's method. (*a*) Place the subject on a table so that the leg hangs freely. Fix an elastic bag by a strap round the thigh, connect this with a Marey's tambour, which writes upon a smoked cylinder moving at 25 cms. per second. Mark the time by a tuning fork at a hundred vibrations per second.

Start the drum, and strike the ligamentum patellæ smartly with a round ruler. The resulting curve should show (1) a small preliminary wave, caused mechanically by the blow, (2) a more prolonged elevation, caused by the contraction of the muscles of the thigh. Measure the 'lost time.'

(*b*) Take a second tracing, using on this occasion a single break induction shock as a stimulus, using unipolar stimulation and placing the electrode directly over the muscles.

Compare the 'lost time' with that of the first experiment.

(*c*) Take a third tracing to test the 'lost time' in the apparatus itself. Place a lever on the muscle bag directly, so as to write immediately under the tambour lever. Take corresponding points when the drum is stationary, then take a tracing with the moving drum by tapping the muscle bag. Measure the lost time, and subtract this from the result in the two preceding experiments.

Tendon Phenomena in the Rabbit (Waller).—A rabbit laid on its back in a shallow wooden trough, unrestrained by any cords, will remain quiet for an indefinite time, in an attitude that is convenient for the study of 'tendon-reflex,' and its comparison with other movements.

(*a*) Connect the leg of a rabbit so disposed by a fine thread to a light lever touching the smoked cylinder. Start the clock, and when the cylinder is at full speed, tap the lig. patellæ with the edge of a paper-knife. A record is obtained, on which the tap and the response can be identified, and the interval of time between them measured.

(*b*) This time should be compared with the time of a true reflex action of the same muscles under the same conditions of observation. To this end it is sufficient to smartly tap the table, or rabbit trough, with a slip of wood, while the cylinder revolves past the recording lever. A rabbit in this state of slight hypnosis gives, at each tap, a slight reflex start, without otherwise agitating itself. The excitatory tap and the muscular response are easily identified on the tracing, and the interval of time between them measured as before.

(*c*) (If desired, the lost time of direct excitation of the same muscles by a break induction shock may be taken, the electrical apparatus being arranged as before).

Spinal Reflexes in the Frog.—Destroy the brain, either directly or by decapitation, leaving the spinal cord intact. Suspend the frog from a clamp by the lower jaw. The carcase will soon hang quite motionless.

Make the following observations.

(*a*) Pinch the toe of one foot with forceps; the leg will be withdrawn. Pinch the toe more forcibly; both legs may now be withdrawn, and the upper limbs may also take part in the movement.

(*b*) Stimulate the foot with (1) single and (2) tetanising shocks. Observe the distance of secondary coil from primary in each case.

(*c*) Place on one flank a small piece of filter paper, moistened with acetic acid. The foot of the same side is raised to rub off the irritant (purposeful movement).

(*d*) If a male frog is employed during the breeding season, it will be found that a gentle touch of the finger on the skin over the sternum will cause the fore limbs to clasp the touching object. This reflex is given from a short isolated length of the spinal cord.

(*e*) Place one foot into 0·1 per cent. sulphuric acid, and note the time which elapses before the foot is withdrawn. Wash off the acid and repeat the observation several times. Take the average time of response (reflex time), compare the times when 0·2 per cent. and 0·4 per cent. sulphuric acid is used. Wash off the acid after each trial with pure water.

(*f*) Place a crystal of NaCl on the optic lobes, and again take the reflex time. It may be considerably prolonged, as the reflex movement is inhibited by the descending excitation.

Action of Strychnine.—Take two decerebrate frogs, place one of the carcases in 0·5 or 0·2 per cent. solution of cocaine hydrochloride, and leave it there for ten minutes. Then inject three minims of a 0·1 per cent. solution of strychnine hydrochloride into the dorsal lymph sac of both frogs.

After 5-10 minutes a slight touch on the skin, or even a jar to the table, will cause inco-ordinate contractions in all the voluntary muscles, in the frog that has had strychnine alone; while in the frog that has been placed in cocaine, a touch is ineffective, and even passive movements of the limbs will cause, at the most, co-ordinate jumping movements of the hind legs.

Destroy the spinal cord—note that all reflex movements cease.

Spinal Reflexes in the Mammal. Certain of the spinal reflexes can be studied in the carcase of a decapitated animal, provided that the arteries of the neck have been ligatured, and the aeration of the blood maintained by artificial respiration. In such a preparation the following effects may be observed:—

(*a*) *The variation of reaction according to nature and locality of stimulus.*

1. *Scratch reflex.*—On rubbing the skin at the back of the neck or on stimulating it with weak induction shocks, the hind limb on the same side may give a series of alternate flexions and extensions.

2. *Flexor reflex.*—A painful stimulus, *e.g.* a prick applied to the fore or hind foot, causes flexion of the limb (*cf.* drawing up of frog's hind limb when dipped into acid).

When this experiment is carried out on the hind limb, the flexion of the stimulated limb may be attended with extension of the hind limb on the opposite side ('crossed extensor reflex').

3. *Push-off reflex.*—Gentle pressure on the pad of the hind foot, so as to extend and spread the toes, may cause extension of the limb.

4. *Knee-jerk.*—The knee-jerk, as we have seen, is probably not a true reflex, but depends on the tonus of the muscles, which itself is reflexly maintained. It can be easily elicited in the decapitated trunk by striking the patellar tendon.

(*b*) *Inhibition of reflex.*

Expose an afferent nerve, such as the peroneal nerve. Elicit the scratch reflex and when it is pronounced stimulate the nerve with weak induced currents. The reflex is at once cut short or inhibited.

(*c*) *Reciprocal innervation of antagonistic muscles.*

Expose the hamstring tendons on one side. Make certain that the knee-jerk can be elicited every time that the patellar tendon is struck. Now draw gently upon the hamstring tendons so as to stretch the muscles. On striking the patellar tendon no knee-jerk is obtained, the tonus of the extensor muscles being reflexly inhibited by the stretching of the hamstrings.

LESSON XXX

RAPIDITY OF A NERVE IMPULSE IN MAN—REACTION TIME TO TOUCH—HEARING—SIGHT—THE DILEMMA

Rapidity of nerve impulse in man. The circuit for this experiment is arranged on the same principle as that for recording a simple muscle twitch (Fig. 10).

In place of a drum it is better to use a pendulum myograph, and in place of the simple striking key, a kickover key is to be used, which will give a single break induction shock, when struck open by the pendulum. The exciting electrodes are of a special pattern. They are made of a metal base covered with wash-leather, which is soaked in salt solution before commencing the experiment. The electrode connected to the kathode of the secondary circuit is large and flat, and is placed on any convenient part of the body; that connected with the anode is a round knob about ¾ in. in diameter. It is provided with an insulating handle, and is applied to the skin over the nerve to be stimulated. Procure a thick rubber tube, closed at one end, and connect the open end with a Marey's tambour, which is arranged to write on the plate of the pendulum myograph. The thick tube is placed in the palm of the hand, so that when the flexor sublimis digitorum contracts, the fingers will compress the tube. Stimulate, (*a*) the median nerve at the bend of the elbow, (β) the same nerve above the clavicle, pressing the electrode deeply down. Take several pairs of tracings, some in reverse order. Take also a control, exciting the nerve twice in the same spot. Mark the time by a tuning fork in the usual way. Examine the tracings produced.

The contraction produced by stimulating the far point of the nerve will start a little later than that produced by stimulation of the near point. Measure this interval on the plate, and calculate the time taken, by the help of the tuning fork curve. It is only possible to obtain satisfactory measurements if the contractions of the muscle have been of approximately the same amount. Locke's cylindrical lens, which can be made by filling pieces of glass tubing with cedar oil, will be found of much assistance in determining the point where the curve leaves the base line. Measure also the distance between the far and near points, and calculate the velocity of the impulse in metres per second. For man the rate is about 60 metres per second.

Reaction time.—This can be measured by means of an electric circuit, or by Waller's method of air transmission.

Experiments. Reaction time to touch.—Place a signal and two simple keys in the primary circuit of an induction apparatus

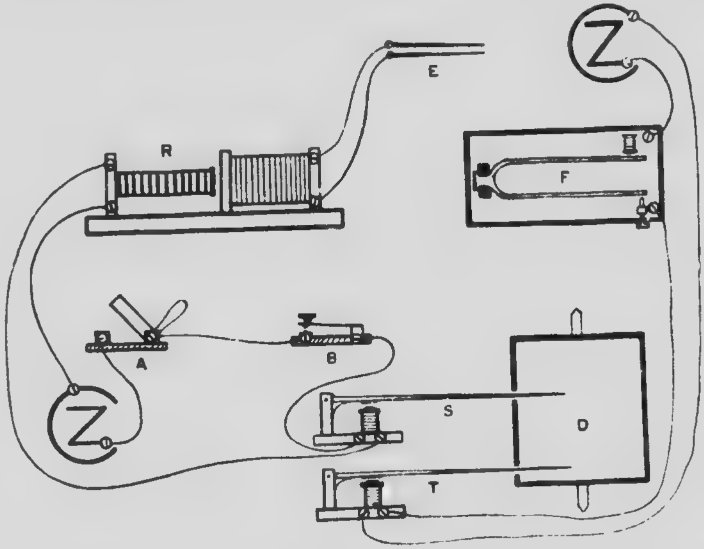


FIG. 30.—Electrical circuit for reaction time to touch. A, experimenter's key; B, subject's key; S, signal, all in primary circuit; E, electrodes in secondary circuit; F, tuning fork; T, time marker; D, drum.

as shown in Fig. 30, and connect a pair of platinum electrodes to the secondary coil. Arrange to record the movements of the signal, and of a tuning fork. Let the subject hold the electrodes against his tongue with one hand, and with the other hand hold the key B closed. Let the experimenter then start the drum, and close the key A. As soon as the subject feels the make shock, let him break the current by opening the key B. Draw ordinates to the curves, and determine the time elapsing between the make and break of the current. Repeat this experiment several times, and take the mean of the results.

Reaction time for hearing.—With the same circuit as in the former experiment, remove the electrodes, E, and place a Morse key instead of the Du Bois Reymond key at A. The experimenter closes the key A sharply, and the subject responds by opening B when he hears the tap.

Reaction to sight.—Use the same apparatus. See that all parts work noiselessly. Place a little flag on the signal, S. Let the subject respond when he sees the flag drop.

The dilemma.—Use the same apparatus as in the first experiment, with the addition of two switchboard keys, and two pairs of electrodes, as in Fig. 6 (p. 12). Place one pair on the moistened forefinger, and the other on the moistened little finger; the subject is to react only when the little finger is stimulated.

Waller's method of air transmission. This is in many respects a more satisfactory method than the preceding. The apparatus consists of a wooden lever resting across a closed india-rubber tube which is connected with a Marey's tambour. This, together with a tuning fork signal, writes on a drum moving at about 5 cm. per second.

Simple reaction time.—(*a*) *Touch.* The subject, blindfolded, rests a finger lightly on the lever. The experimenter taps the finger, and the subject presses the lever as soon as he feels the tap.

(*b*) *Hearing.* The subject sits as before, and the experimenter strikes the lever with a small bell from which the clapper has been removed.

(*c*) *Sight.* A screen, through which the white end of the lever protrudes, is placed so as to conceal the rest of the apparatus, and the subject presses the lever as soon as he sees it move.

Discrimination time.—The apparatus for this has two levers which lie across the same tube. The experimenter gives two signals, either touch, hearing or sight, and the subject is to answer to a chosen one only of these.

Volition and choice time.—The subject places the right hand on one lever, and the left hand on the other, and only answers with the left side when that side is stimulated by either touch, hearing, or sight. The average of ten observations is to be taken for each experiment.

LESSON XXXI

CEREBRAL LOCALISATION. DEMONSTRATION

Anæsthetise the animal, and arrange that the anæsthesia shall be uniform throughout the experiment, preferably using some form of regulating inhaler. Tracheotomise. Place the animal with the back uppermost. Reflect the edge of the temporal muscle, so as to expose the skull on one side of the median line, over the posterior part of the frontal lobe and the anterior part of the parietal lobe of the cerebrum. Trephine the skull at the parietal bone. Enlarge the opening gradually by chipping away bone and occlude the bleeding vessels with soft wax, until the area of the hemisphere about the sulcus cruciatus has been fully exposed. Reflect the dura mater. Apply a warm cloth, and wait until the bleeding has ceased. The fore and hind limbs of the opposite side should now be unfastened, and allowed to hang free.

Cut off the hair from any convenient part of the body and fasten on it a large flat electrode from the secondary of an induction coil. The other electrode is in the form of a finely pointed needle, and is applied gently to the cortex. Stimulate with weak tetanising shocks.

SPECIAL SENSES

LESSON XXXII

CUTANEOUS SENSATION—GUSTATORY AND OLFACTORY SENSATIONS

Cutaneous Sensation.—In all the experiments on special senses one student should act as subject and another as experimenter; they should reverse places at each successive series.

Touch.—Use von Frey's bristle æsthesiometer.

This consists of a handle holding a fine bristle, hair, or glass fibre. The pressure exerted by the bristle can be measured by an ordinary chemical balance. Let the subject close his eyes, and the experimenter test the pressure required to give a feeling of touch on various parts of the body, *e.g.* the tip of the tongue, lips, tip of finger, palm of hand, back of hand, back of forearm. Notice how the presence of hairs modifies the result. Observe further that when a fine fibre is used in the æsthesiometer the sense of touch is not distributed evenly over the skin, but is localised in 'touch spots.' One or more such spots are almost invariably to be found associated with each hair.

Very gently touch the surface of the cornea with a clean glass fibre—an unpleasant sensation will be felt that is not touch, cold, or warmth, but is more allied to pain; most observers therefore come to the conclusion that touch spots are absent from this place.

The sense of touch can also be examined by means of a standard camel's hair brush, 0·5 cm. long and 0·5 mm. wide at the base (Trotter and Davies), or a wisp of cotton wool (Head); but these methods are more useful in examining the result of nerve section than on the normal skin.

Weber's Compass Æsthesiometer.—This has two blunt metal points, which can be set at varying distances apart, measured by a millimetre scale.

Experiment.—Test the same regions as before, and measure the smallest distance at which a double impression is perceived from the two points. As in all experiments of this kind, interpose single touches at irregular intervals, so that the subject will not deceive himself, but will answer from his actual sensations.

Compare the result obtained in this way with that given by von Frey's bristles.

Cold Spots. Using very light pressure, stroke the back of the hand with a smooth, blunt-pointed instrument, that is at least 8° lower in temperature than the skin. For the preliminary experiments a lead pencil answers the purpose very well. At certain spots the point will give a sensation of cold quite distinct from that of touch, which latter sensation is absent from the cold spot.

For accurate work use the Kronecker-Miescher æsthesiometer. This instrument consists of a conical tube of German silver, which has a median partition, incomplete at the tip. Water can be conducted through the tube, flowing round at the tip of the cone through the gap in the partition. The temperature is read off on a little thermometer. The end of the cone in contact with the skin is a circular plate of thin platinum, 1 mm. in diameter. Goldscheider, and more recently, Trotter and Davies, have used a series of copper cylinders, 6 mm. in diameter, terminating in a short process, 1 mm. in diameter. These are heated or cooled to any desired temperature, and applied to the skin.

Warmth Spots.—Repeat the experiments, using the Kronecker-Miescher instrument, with water at about 38°, or else Trotter and Davies' cylinders. Map out the warmth spots, and note that they are fewer, more diffuse, and have a longer latent period, than the 'cold' spots. It is inferred that the end-apparatus is situated deeper in the skin.

Pain Spots.—Use a fine needle, or the Trotter-Davies hair algometer (Fig. 31). This is essentially a fine needle, held in a vertical guide, which can be pressed on the skin by means of a von Frey hair.

The needle must be applied vertically and the whole instrument depressed till the head of the needle has risen about a quarter of an inch. Search for pain spots with this apparatus.

Apply the broad end of a cylinder heated to 50° to the skin, note that it feels *hot*, a sensation compounded of 'warmth' and 'pain.' Test the inside of the cheek opposite the molar teeth. 'Touch,' 'cold,' and 'warmth' spots are present but pain spots absent.

Complete these observations by examining microscopic sections of (*a*) the skin of the forefinger; (*b*) the skin of the forearm; (*c*) the cornea; (*d*) the cheek; (*e*) the glans penis. Compare the number and distribution of the various end-organs seen in each section. It has been suggested that Meissner's corpuscles and the nerve-endings in the papillæ of the hairs serve the sensation of touch; 'end bulbs,' that of cold; Ruffini's end-organs, placed more deeply in the skin, that of warmth; while the free nerve filaments ramifying amongst the superficial epithelial cells are affected in the sensation of pain.

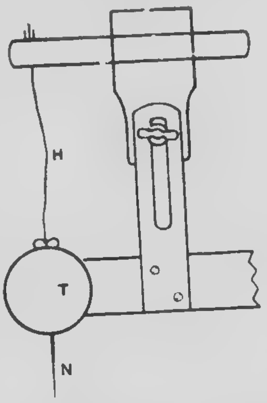


FIG. 31.—Trotter-Davies hair algometer. T, thumb-piece; N, needle; H, von Frey hair.

Taste.—For testing sensations of taste use the following solutions—Quinine bisulphate 1 per cent. (bitter), cane sugar 5 per cent. (sweet), sodium chloride 10 per cent. (salt), acetic acid 1 per cent. (sour). The tongue of the subject is wiped dry with a tuft of cotton wool, and the solutions are applied with a fine-pointed brush. Test in this way with the four solutions the (*a*) tip, (*b*) the sides and (*c*) back of the tongue. The subject writes the sensations experienced on a slate, as, if the tongue be withdrawn to speak, the substance is thereby spread over a wide area.

Next test the sensations received from single (fungiform) papillæ, using the same four solutions.

Effect of *Gymnema sylvestris.*

Apply a 5 per cent. decoction to a small area of the tongue; after half a minute rinse out the mouth and test the affected area. Sweet and bitter sensations will have disappeared, saline and sour remaining unimpaired.

Smell.—The acuteness of the sense of smell can be measured by means of Zwaardemaker's olfactometer. This consists of a tube which is passed into the subject's nostril, a screen being interposed, so that he cannot see the material experimented with.

A tube treated with an odorous substance slides upon the outside of the nasal tube, at its distal end. The length to which it must be drawn out to obtain a just perceptible smell, gives a measure of the acuteness of the subject's olfactory sense. The unit or 'olfactie' is the odour given off by 7 mm. of india-rubber tubing.

Experiments.—(1) Determine the acuteness of smell with the olfactometer.

(2) Let the subject first make himself apnœic by taking several forced respirations. Then let him shut his eyes, and bring up to his nostrils an open wide-mouthed bottle, containing strong ammonia or spirits of camphor. He will feel a pricking sensation, but no smell. Then let him close the nostrils, remove the bottle and take the gentiest possible sniff, and note the change in the sensation.

(3) Let the subject smell various substances, and note the difficulty of classification.

(4) Study the effect of mutually antagonistic smells. With a double olfactometer, lead separately into the right and left nostril the vapour of

(*a*) Caoutchouc and paraffin,
(*b*) Ammonia 1 per cent. and acetic acid 2 per cent.

When the substances are accurately balanced no smell is perceived.

(5) If the laboratory possesses a small room that has well-fitting doors and windows, the student can attempt an estimation of the smallest quantity of an odorous substance that can be detected. Measure the cubic capacity of the room. Weigh very carefully by counterpoise a small stoppered bottle of mercaptan. Let the experimenter take this into the room, while the subject waits outside. The experimenter opens the bottle for a few moments, closes it, and stirs the air vigorously with two large fans. The subject then enters the room and sniffs about 50 cc. of the air. The process is repeated until he can just smell the substance.

Fischer and Penzoldt give 217×10^{-11} milligrams as the smallest perceptible weight of mercaptan.

LESSON XXXIII

EXPERIMENTS ON THE AUDITORY SENSE AND THE SENSE OF EQUILIBRIUM

Hearing. Examine several sources of sound that give a musical note: *e.g.* a tuning fork, violin string, trumpet, human voice.

Observe that musical notes differ in

(*a*) Pitch, dependent on the wave-length of the vibrations of the air.

(*b*) Loudness, dependent on the amplitude of the wave.

(*c*) Timbre, dependent on the character of the wave.

The pitch of audible notes.—Verify on a stretched violin string that, for any given string, the pitch of the note emitted varies

(1) Inversely as the length of the string.

(2) Directly as the square root of the tension.

For different strings the note varies inversely as the diameter of the string, and inversely as the square root of its density.

Examine the limits of pitch that can be heard by the human ear. The higher limit is given by means of Galton's whistle. Let each student determine his own limit, taking the precaution of keeping the pressure of air supplying the whistle constant. It usually is about 22,000 vibrations per second.

The lowest limit is about 15 to 20 vibrations per second.

Smallest perceptible difference of pitch.—Determine the smallest interval of pitch that can be detected, using two tuning forks, of which one remains constant and the pitch of the other is varied by means of a sliding clip. A trained ear can detect, in the middle of the range of audible notes, a difference as small as 0·2 vibrations per second, which is approximately equal to one sixty-fourth of a semitone. Higher in the scale the smallest perceptible difference is much greater. Let the student attempt to measure this 'differential threshold' for vibrations between 15,000 and 20,000 per second with Galton's whistle.

Interference of tones or 'Beats.'—Strike simultaneously two tuning forks of identical pitch. The tone sensations are exactly uniform. Now alter one fork very slightly, by sliding the clamp the tone is no longer uniform, but swells and falls in loudness it 'beats.' These beats are due to the interference of the sound waves from each fork. It can be shown that when one fork gives x vibrations per second, and another $x + y$ vibrations per second, there will be y beats per second.

Resonance.—Hold a tuning fork over the appropriate resonator—the latter will respond by giving out the same note. Slightly alter the pitch of the fork by sliding the clamp, and note that the resonator is now silent.

Determine by means of a small whistle the resonance of the tone of the external auditory meatus. It is about the note f^{iv}. When the proper note is reached the sound appears to have a peculiar piercing character. Insert a piece of rubber tubing about half an inch long into the meatus of both ears and note that the resonance tone changes.

The membrana tympani has very feeble power of resonance, due to the curvature of the surface.

Loudness.—Threshold value of sound.

Close one ear with cotton wool and determine the distance at which a watch can be heard by the other ear. Note the varying distinctness of the sound when just at the threshold.

Timbre.—Compare the different quality of the sound given when the same note is emitted by various musical instruments. The character depends on the addition to the simple sine wave vibration of the primary tone, of other vibrations, usually bearing certain simple relations to it. Some of these are easily recognised. Pluck the violin string, and as it vibrates gently touch the middle of the string with a feather. The string will then vibrate with a node in the middle, and will emit a tone of twice the frequency of the primary the octave.

Again pluck the string, let it vibrate simply, and listen carefully; the octave can be heard as well as the primary note. Several other overtones can be detected with practice.

Noises.—Strike the table with a stick—a noise is produced; that is, a tone where the vibrations have no simple relation to each other.

Slow vibrations also produce the sense of noise. Hold a tongue of metal against the cogs of a toothed wheel and gradually rotate the latter—a clattering noise is produced which becomes a more or less definite note as the speed of the wheel is increased.

Membrana Tympani.—To observe this structure in man, the student fastens the laryngoscope minor on his forehead so as to throw the light into the exterior auditory meatus. He then very gently inserts a speculum, pulling the pinna upwards and backwards, when the membrana tympani comes into view. This will appear tense, smooth and semi-transparent. The centre or *umbo* is more retracted than the rest, and passing upwards and slightly forwards from this, will be seen the handle of the malleus. This terminates near the upper margin in a prominence, the short process of the malleus; from this point short folds pass forwards and backwards, between these folds is the *membrana flaccida*. A triangular cone of light will be seen passing from the *umbo* forwards and downwards—this is the reflection of the light used in examining the meatus.

LESSON XXXIV

DISSECTION OF EYE—THE EYE AS AN OPTICAL INSTRUMENT—ARTIFICIAL EYES—RETINA—FUNCTIONS OF THE IRIS—ACCOMMODATION

Physiological anatomy of the Eye. Examine the fresh eye of an ox or sheep. Identify the cornea, sclerotic, the muscles of the eyeball, the conjunctiva, and the optic nerve. Look through the cornea and see the dark brown iris, which leaves a vertical pupil.

Remove the adherent fat, and make a V-shaped incision into the sclerotic; the wide ends of the V terminating near the sclero-corneal junction. Carefully peel up the sclerotic, and notice its dark *lamina fusca*. The choroid coat now comes into view, covered near the sclero-corneal junction by the pale fibres of the ciliary muscle. Peel off the choroid in its turn, and see the pale retina lying within.

Cut the eye in two, under water, by means of a circular incision, so as to divide it into an anterior and posterior half. In the latter note the retina, usually detached from the choroid. and the optic disc, where the fibres of the optic nerve leave the eyeball. Observe the retinal artery and veins radiating out from this over the surface of the retina. In the anterior half of the eye, identify the vitreous humour, the crystalline lens, with its suspensory ligament, and the ciliary processes.

The Eye as an optical instrument. *Formation of images on the retina.*—Make a little window in the posterior part of another bullock's eye, removing carefully the fat, sclerotic and choroid, leaving the retina. Turn the cornea towards an incandescent lamp, and observe that there is a clear inverted image on the retina. Move the eyeball towards the lamp, the image enlarges and becomes blurred, as the dead eye is adjusted for distant vision. Place a weak convex lens in front of the cornea; the image can again be focussed on the retina.

This experiment can be more elegantly performed on the eye of an albino rabbit, as in this case no dissection is required.

Examine the various forms of artificial eye provided, and identify the parts supposed to correspond to the living structures. The small eyes made by Hardy are very convenient for many experiments; they can be made emmetropic, myopic, or hypermetropic at will, and the formation of images and circles of diffusion easily studied.

Kühne's artificial eye.—Repeat the above experiment with Kühne's eye. This apparatus illustrates very well the additional point, that the most powerful refractive surface in the eye is the front of the cornea, the lens although more curved having less refractive power, as the amount of refraction of any given lens is proportional to the difference of the refractive indices of itself and the medium in which it is placed.

Perception by the retina.—The student should next examine the different parts of his own retina. For most of these experiments he will require to learn the art of looking directly at a fixed spot and attending to the sensation produced by other spots. This is not difficult after a little practice.

(*a*) *The macula lutea.*—Close the eyes for about half a minute, and then open them so as to look at a white surface or a clear sky through a flat-sided bottle containing a solution of chrome alum. A rose-coloured elliptical spot will be seen on a blue-green ground.

(*b*) *The fovea centralis.*—This is the area of most distinct vision, which subtends an angle much less than might be expected.

Close one eye, fix the gaze of the other on the centre of a word of five letters in this page. If the eyeball does not move only one word is distinct enough to be read.

Determine the acuteness of vision at the fovea by measuring the minimum angle at which letters can be read, using Snellen's test types. The normal eye should recognise a letter subtending not more than five minutes of arc. The result is stated in ophthalmic practice as a fraction, the numerator being the standard distance for examination (6 metres), the denominator the distance at which the normal eye can distinguish the smallest letters that the eye to be tested can identify at the standard distance. The angular distance apart at which two lines can be seen separately, is about one minute of arc, which approximately corresponds to the distance between the centres of two adjacent cones on the retina.

(*c*) *The peripheral part of the retina.*—This, though the images are less distinct, is more sensitive to light than the fovea. Examine by Gotch's modification of the spinthariscope. In the country it is easy to verify the observation on the fixed stars—many more stars are visible by indirect vision than when they are looked at directly.

Moving objects are much more readily noticed at the peripheral parts of the retina than are stationary ones. Fix the vision on any spot, and notice how stationary objects near the edge of the visual field are neglected, while any movement is observed at once.

(*d*) *The blind spot.*—The optic disc, where the optic nerve leaves the eye, is quite insensitive. Fix one eye as before, close the other and stand at arm's length before a black-board, keeping the head motionless. Take a piece of chalk in one hand and map out the blind spot.

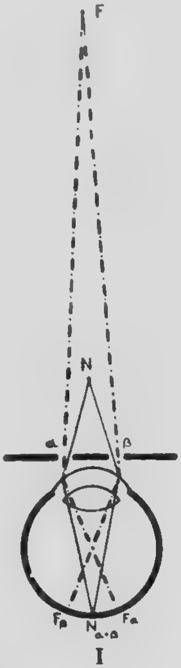
Functions of the Iris. Pupillometry. During strong illumination the iris contracts, diminishing the size of the pupil, so cutting off the marginal rays of the cornea and lens, and diminishing spherical and chromatic aberration. During feeble illumination the pupil expands.

Experiments.—The subject covers both eyes with his hands for a few moments, and removes them quickly—the pupils will be seen to contract rapidly.

The pupil also contracts with the act of accommodation. Let the subject look at a distant object, and suddenly accommodate for a near object—the alteration in size is readily seen.

The student can readily perceive the changes in size of his own pupil, under different conditions, by means of Fick's entoptic method. Take a thin card, make a fine hole with a needle, and hold the card close to the eye; the hole will be seen as a diffuse circle which varies in size with the size of the pupil. Make two holes at such a distance that the two circles just touch, under ordinary conditions of light and relaxed accommodation. Diminish the illumination—the two circles will overlap. Throw a bright light into the other eye—the circles separate. Accommodate for a near object—the circles separate. Measure the distance between the pin holes in each case that gives circles which just touch.

Accommodation.—The normal human eye, when at rest, focusses exactly on the retina rays of light coming from a distant object, which are practically parallel. The rays of light from a near object are slightly divergent; to focus these on the retina, the refractive power of the eye must be increased. This is accomplished in man by the relaxation of the suspensory ligament, so that the lens becomes more convex by virtue of its own elasticity. Near and far objects, therefore, can be seen distinctly in succession, but not simultaneously.



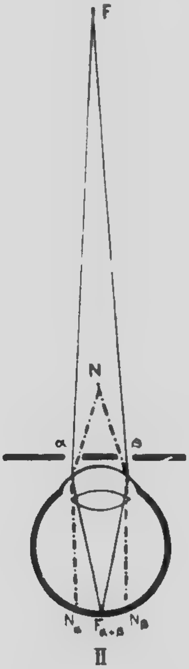


Fig. 32.—Scheiner's experiment. I. gives the course of the pencils of light when the eye is focussed for the near point, N; II., the paths when the eye is focussed for a distant point, F.

Experiments. — Place two small objects so that one is about twelve inches from the eye, and the other about 15 feet; observe that either is distinct but not both at once.

Limits of Accomodation.—Determine these by means of Huizinga's Punctumeter. The far point is for a normal eye at an infinite distance. The near point varies with the eye of the subject. In the punctumeter the far point is brought close to the eye by means of a convex lens, and its distance then measured on a scale, which is so calculated as to read the refraction of the eye directly in + or − diopters, allowance being made in the calculation for the effect of the convex lens.

The distance between far and near points gives the range of accommodation.

Scheiner's Experiment.—This illustrates both accommodation, and the inversion of the retinal image. Take a card, or better, a thin metal plate, that has in it two small holes, at a less distance apart than the diameter of the pupil.

Take two other cards. In one make a smooth round hole 2 m.m. in diameter. Place it either against the window or a lamp, at about 10 feet distance. Hold the plate with the two small holes close to the eye, and look at the brightly illuminated hole—it appears single; now accommodate for the finger held near the eye—the image of the illuminated hole becomes double (see Fig. 32, No. I).

Slide a visiting card so as to occlude one hole in the plate; for example, the right hand hole β in I. The right hand image will disappear. This is because the *left* hand image F β on the retina has been abolished, in consciousness. Therefore the *right* hand image seems to vanish, since it is projected through the nodal point.

Perform the converse experiment by pricking a small hole in the second piece of card, and placing this between the eye and the light, close to the near point. Accommodate for infinity. A double image of the hole will appear as before, but on occluding the right hand hole (β) in the metal plate the left hand image now disappears (see Fig. 32, No. II).

Changes in the lens during accommodation.—When the suspensory ligament is relaxed, the anterior surface of the lens becomes more convex, the radius of curvature changing from 10 m.m. to 6 m.m. The posterior surface is less affected, the radius changing from about 6 m.m. to 5 m.m. The anterior surface of the lens bulges forward, the range of movement being about 0·5 m.m.

Experiments.—The subject accommodates first for infinity, and secondly for a near object, keeping the optic axis fixed. The experimenter looks at the eye in profile, and observes that the iris is bulged forwards by the change in the lens. The pupil also contracts as has been mentioned previously.

The Phakoscope. Sanson's images.—This is essentially a triangular box, at one corner of which two prisms make three pairs of images of a bright light (the filament of a Nernst lamp is a suitable object to use) on the eye of a subject. The images are reflected from (*a*) the anterior surface of the cornea, which gives a bright, erect, virtual image; (*b*) the anterior surface of the lens; this gives a dim, erect, virtual image, apparently deeper in the eye than the other; (*c*) the posterior surface of the lens, which gives a dim, inverted, real image. When the observer has made out these three pairs of images, the subject accommodates for a near object without shifting the optic axis—(*a*, is unchanged; in (*b*) the two images become smaller and closer together; in (*c*), under ordinary conditions, no change can be dete ·ed, though there is in reality an alteration of the same kind as in (*b*), but much less in amount.

If the student has any difficulty in seeing these images, he can construct a model of the refracting apparatus of the eye by placing a watch glass a little in front of a bi-convex lens. Examine in a dark room the images of a candle reflected from (*a*) the anterior surface of the watch glass; (*b*) the anterior surface of the lens; (*c*) the posterior surface of the lens.

LESSON XXXV

DEFECTS OF THE EYE—COLOUR VISION—CONTRAST AFTER-IMAGES

Defects of the Eye.—The normal eye suffers from two defects, spherical aberration and chromatic aberration.

Spherical Aberration.—This can readily be seen in Kühne's artificial eye, or demonstrated on the human subject by means of atropine.

Place one drop of 0·1 per cent. solution of atropine sulphate in one eye (*e.g.* the right), and wait for 20 minutes. When the iris is fully dilated, look at a moderately bright object at a considerable distance, with each eye separately. Note that, with the right eye, the object looks much brighter, but that on account of spherical aberration its edges appear blurred. Compare the appearance seen with the left eye only, from which the 'Iris diaphragm' has not been removed.

Chromatic Aberration.—In the eye, as with other simple combinations of lenses, the focus for the blue end of the spectrum lies a little closer to the lens, than that for the red end.

(1) *Gotch's Experiment.* This is a particular application of the method suggested by Helmholtz.

An incandescent electric lamp is viewed through a suitable thickness of cobalt glass, a pin-hole stop being placed between the glass and the eye. A carrier is fitted, to allow a collimating lens to be inserted between the glass and the lamp.

Observe the following facts:

If the object is five or six feet from the observer (*i.e.* well beyond his near point), two filaments are seen, one red, the other violet-blue. The red one is the more distinct, the blue is on one side, and is blurred.

On moving the carrier and stop from side to side in front of the eye, the red sharp image remains fixed, whilst the blue one moves, the motion being in the same direction as that of the pin-hole, thus showing that the violet-blue rays are focussed in front of the retina.

Hypermetropic observers may easily get within the near point, at a distance of a few feet. The blue image may now become distinct, and the red one broad and ill-defined.

On moving the diaphragm the blue image is steady, while the red one moves in the opposite direction to the motion of the pin-hole, indicating that the red rays are focussed behind the retina. In a normal individual the same result may be obtained by using an appropriate biconcave lens.

If the lamp be situated at the near point, then both red and blue images sometimes appear equally distinct, but both have ill-defined margins. On moving the pin-hole from side to side, both images move, so as to diverge from or approach one another.

(2) *von Bezold's Experiment.*—Place Fig. 33 close to the eye and look at it with imperfect accommodation. The white circles seem no longer colourless, but to most people appear pinkish blue, though to some they assume a yellowish tint.

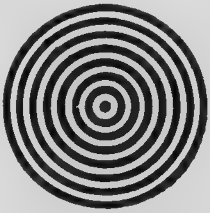


Fig. 33. von Bezold's circles. To show chromatic aberration.

Errors of Refraction. Myopia.—In the normal or emmetropic eye, at rest, parallel rays come to a focus on the retina. In the myopic eye the refractive apparatus has approximately the same curvature as the normal, but the antero-posterior diameter of the eyeball is lengthened. The retina is therefore too far back, and parallel rays from a distant object come to a focus in front of the retina. As the object approaches the eye, a point is reached where the divergence of the rays compensates for this. A myopic eye, therefore, has a far point at a finite distance. It also has a near point, when the accommodation is brought into play.

Experiment.—In a class of ordinary size two or three members will usually be distinctly myopic. Measure their far and near points with the punctumeter. The student can imitate this condition by placing a convex spectacle lens in front of his own eye, and perform the same experiment for himself.

Hypermetropia.—This condition is the converse of the preceding, the antero-posterior diameter of the eye being too short for the refractive apparatus. When the eye is at rest, all objects at any distance are more or less indistinct. By accommodating an exact focus is obtained up to the near point, which is naturally further from the eye than in the emmetropic condition.

Determine the near point in a hypermetropic eye, or reduce a normal eye to this condition by a concave glass, and measure the result.

Presbyopia.—As age advances, the lens becomes less and less elastic, and the power of accommodation correspondingly diminishes. This is most readily demonstrated by ascertaining the near point of the eye. For example, this is normally 10 cms. at the age of twenty, 14 cms. at thirty, 22 cms. at forty, and so on.

Determine the near point for members of the class who are of different ages, by the punctumeter.

Astigmatism.—This term is employed for two kinds of defect: namely, for irregularities of cornea or lens, producing irregular astigmatism, as when a luminous point has star-like rays, or for differences in the refraction of different meridians of the eye—regular astigmatism, producing the same result as if a weak cylindrical lens were placed in front of the eye. Examine the target of the punctumeter, when a lens of this description is placed in front of the eye.

Demonstration of Errors of Refraction with Kühne's Eye.—This apparatus is particularly well adapted for studying these errors. As the lens is of glass, it is perfectly presbyopic, and by sliding the screen, which represents the retina, to and fro, myopia and hypermetropia are readily imitated. Astigmatism is caused by the addition of a cylindrical lens outside the eye.

Colour vision.—There are three things to be considered with regard to any given colour sensation

(1) Colour or hue.
(2) Saturation or tint.
(3) Intensity or brightness.

Variation in colour.—The colour depends on the wave-length of the light.

Examine the spectrum from a prism; the blue end is the most refracted.

Colour blindness.—Examine portions of the spectrum by the method of Edridge-Green. When the portion is shortened sufficiently, it appears mono-chromatic. Measure the length of this monochromatic patch for each individual, in different parts of the spectrum; in 'colour-blind' persons the length will be greater than the normal, being exactly proportional to the defect of colour vision.

Examine Holmgren's set of coloured wools, and let one student test his neighbours for colour blindness. This test succeeds best if both experimenter and subject are slightly thick-headed.

Saturation of colour.—Use Rothe's rotatory apparatus. This consists essentially of a disc that can be rotated at different speeds. This disc has differently coloured sectors, and by means of radial slits any required mixture of colours can be made.

Examine first a pure red disc; secondly the same red disc with a white sector, using a fast rotation to avoid flicker.

Variation of intensity. Observe the difference in sensation given by any pure colour, with different intensity of illumination.

Compare the relative intensity of different colours with the same illumination; the same difficulty will be met with as was found in comparing the intensity of sounds having a marked difference in pitch. With medium illumination, take red and blue cards that appear of the same degree of brightness. Bring them into a bright light—the red appears the more intense. Reduce the illumination—in dull light the reverse occurs.

The dark-adapted eye.—The student should make experiments at home on the eye in this condition. With a very feeble illumination, note that all colour sense is absent—all objects when just visible, have apparently the same pale bluish-green glimmer.

Look carefully at a small marble at about 3 feet distance, with the dark-adapted eye, in very feeble illumination. When the image falls on the yellow spot it becomes invisible.

Contrast.—Simultaneous contrast occurs when different intensities of light fall side by side on the retina.

1. Take a large sheet of white paper and another of black, place them side by side, and place in the middle of each,

small similar pieces of grey paper. Note which appears the brighter.

2. Take a sheet of red paper. Place in the middle a square of grey paper, and cover the whole with tissue paper. Note the colour now assumed by the grey patch. Repeat with a sheet of pale green paper.

Colour shadows.—Arrange an 8 cp. and a 16 cp. electric bulb about 6 inches apart, and place an upright rod so as to throw two shadows on a screen about a yard away. Each shadow is therefore illuminated by the other lamp; in this case both are slightly yellow. Next, place a piece of coloured glass in front of the 8 cp. lamp; the shadow of the rod given by this lamp becomes of the complementary colour. The colour is most vivid when the shadows nearly touch.

Succession contrast.—Make several rings of different coloured papers, place a small black dot in the centre of a sheet of white paper, put the ring over this, and look steadily at the dot for two minutes. Brush away the ring, continuing to gaze at the dot; an after-image of the ring will appear of the complementary colour.

Mixture of Colours.—With Rothe's apparatus take any coloured disc, and determine what other colour must be taken to produce grey or nearly white.

After-Images.—These are of two kinds. In the first, or positive after-image, the original object is reproduced of the same degree of brightness; in the second, or negative after-image, the brightness is reversed. The colour of the negative after-image is always complementary to that of the original object; that of the positive after-image may be either complementary or of the same colour. Generally speaking, positive after-images are most easily obtained after a short exposure of the rested eye, negative after-images by a comparatively long exposure.

Experiments.—1. Close the eyes for a minute or two in order to rest them. Look at an incandescent electric light through ruby glass for about half a second, close the eyes again, and a bright red, positive, after-image will be perceived.

2. Look at the light again for about half a minute. On closing the eyes a bright green image will be perceived.

3*a*. Study the effect of the background on which the images are seen. Look at the light for half a minute, then direct the eye to a plain white surface. A dark negative after-image will be perceived.

3b. Repeat, but in this case look at a dark surface; the after-image will now be positive.

Note the changes in colour which these things show. Note also the effect of blinking the eyelids. In experiment *3a* the negative after-image becomes converted to the positive when the eyes are shut, to become again negative when the eyes are opened.

LESSON XXXVI

THE OPHTHALMOSCOPE—RETINOSCOPY

The Ophthalmoscope. This consists essentially of a concave or plane mirror, which reflects the light of a lamp into the observed eye; a hole in the middle of the mirror allows the observer to look into the pupil in the same direction as the rays of the light travel, which illuminate it.

The student should practise both direct and indirect methods on the artificial eye in the first instance, and afterwards on the human subject.

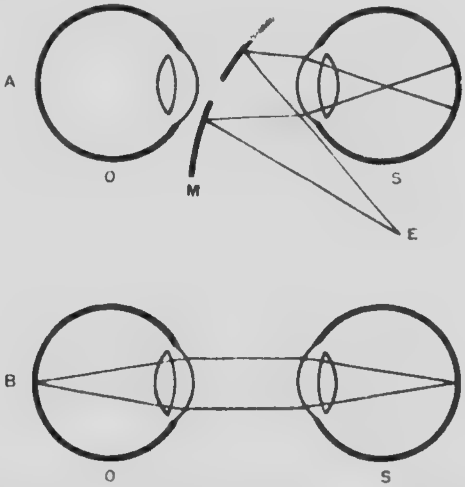


FIG. 34. Ophthalmoscope. Direct method. Fig. A gives the course of the rays of light from the lamp. Fig. B the rays forming the image on the observer's retina. E, lamp; M, mirror; O, observer's eye; S, subject's eye.

In the direct method of observation a small concave mirror of 6 cms. focus is employed. The source of light, which may be an argand burner or incandescent electric lamp with a frosted bulb, is placed on a level with the observed eye, and a little behind it on the same side. The observer's eye and the mirror are then placed as close to the observed eye as can be conveniently done. On directing a beam of light from the mirror into the eye, the rays take the course shown in Fig. 34 A, converging from the mirror and being brought to a focus by the refracting surfaces of the eye, in the vitreous humour a little distance beyond the lens, thus diffusely lighting up a portion of the retina. Assuming that observing and observed eyes have no error of refraction, and that their accommodation is relaxed, the rays of light from any point of the observed retina will take the course shown in Fig. 34 B, emerging from the eye parallel and being brought to a focus on the observer's retina. As the retina is observed near the principal focus of the dioptric system of the observed eye, this acts as a simple microscope and a magnified, erect, virtual image seen apparently some distance behind the observed eye. This image in the normal eye is enlarged about × 15, but only a small part of the fundus can be seen at one time.

To get a more general view of the retina the indirect method must be employed. The concave mirror of 22 cms. focus is employed and the lamp being in position above described, the observer places his eye at convenient arm's length from the eye to be examined, and throws the converging beam of light from the mirror upon it. A double convex lens of about 7 cms. focus (L) is held by the left hand just in front of the observed eye, and the light directed through it. The rays converge to a focus just behind the crystalline lens in the vitreous humour, and illuminate the interior of the eye as shown in Fig. 35 A.[1] The path of the rays forming the image of the retina is shown in Fig. 35 B. The rays from any given point on the retina, on passing out of the eye, become parallel, and these parallel rays, on passing through the lens, converge once more to a point at its principal focus, forming an inverted real image, which is seen by the observer just beyond his near point.

At first on throwing the light into the eye a red glare will be seen filling the pupil. This is called the reflex. If the lens be now moved away from the observed eye, until the margin of the pupil disappears, and the observer's eye be accommodated for the principal focus of the lens, the reflex will suddenly be replaced by a sharp image of some of the retinal blood-vessels. By causing the subject to look slightly inwards and upwards, the optic disc will become visible, as an oval pale pink area, through the middle of which the central artery of the retina will be seen entering and breaking up into its various branches.

---

[1] This diagram supposes that a concave mirror of 22 cms. focus is employed, that the light comes from a source a little behind the patient's head, and that the observer's eye is at the usual distance from the subject of 23 cms.

To observe the macula lutea, the subject should look straight at the hole in the ophthalmoscope mirror, but the strong light falling on this most sensitive part of the retina will cause the pupil to become contracted, unless the eye is under the influence of atropine. The peripheral parts of the retina can be observed by causing the subject to look up and down and right and left as the case may be, as far as possible, the head being kept motionless and the eye alone rotated.

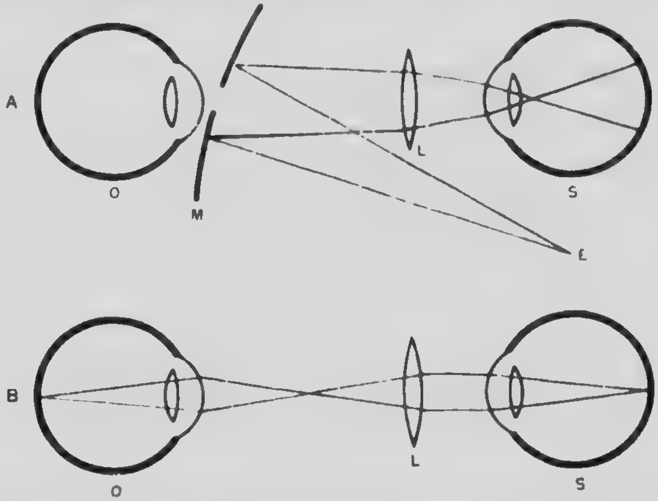


Fig. 35. Ophthalmoscope. Indirect method. Fig. A gives the course of the rays of light from the lamp. Fig. B the rays forming the image on the observer's retina. E, lamp; M, mirror; L, lens; O, observer's eye; S, subject's eye.

Estimation of Refraction by the Ophthalmoscope.—In the direct method of examining the retina, it was seen that, when the accommodation of both observer's and subject's eye was relaxed, a clear image was seen only if both eyes were emmetropic. This forms the basis of a method of ascertaining errors of refraction.

If the observer's eye be emmetropic, or its error corrected by a suitable lens, and the accommodation relaxed, he can at once determine the error of an observed eye by noting which lens of the refraction ophthalmoscope has to be brought over the hole in the mirror, in order to get a clear image of the retinal details.

If the observed eye be hypermetropic, the fundus can be seen by an effort of accommodation, as the emerging rays diverge. As convex lenses of increasing curvature are successively employed, the observer's accommodation can be relaxed, and the correcting lens for the observed eye is the most convex one with which the fundus can be distinctly seen.

The emmetropic observer cannot see the fundus in myopia without a correcting glass, as the emerging rays converge, and come to a focus in front of his retina.

The weakest concave lens which enables the fundus to be distinctly seen, is that which correctly compensates the myopia of the observed eye.

Retinoscopy.—*The shadow test.*

The observer, using a concave mirror of 22 cms. focus, sits 120 cms. in front of the subject. The source of light is placed over the latter's head. The light is thrown into the eye at an angle of 15° to the visual axis, to avoid stimulating the macula lutea, and the consequent contraction of the pupil.

When the mirror is rotated in different directions, the illuminated spot on the retina is seen through the refracting media of the eye to move across the pupil. Observe the motion of the edge of this, technically called 'the shadow.'

If the shadow move with the mirror, myopia is present. The eye is illuminated by the real inverted image I_1 of the lamp L in the focus of the mirror M (Fig 36). This image moves with the mirror. An image I_2, again inverted, of I_1 is formed on the retina distinctly, if I_1 is at the far point, otherwise blurred. This retinal image will move in the opposite direction to I_1; thus if I_1 move to I_3, I_2 will move to I_4. I_2 and I_4, however, cannot be seen by the observer, as all the rays from them converge again on leaving the eye, to form a third set of real images, near I_1 or I_3, inverted, and having the same direction of motion as the latter, *i.e.* with the mirror.

In emmetropia the retina R is nearer the lens, and the path of the rays is shown in Fig. 36 B.

The rays from I_1 do not come to a focus on the retina, but behind it, and hence a circle of diffusion D_1 is formed on the retina. The rays, on emerging from the eye, become parallel, and hence a virtual image is formed at infinity,

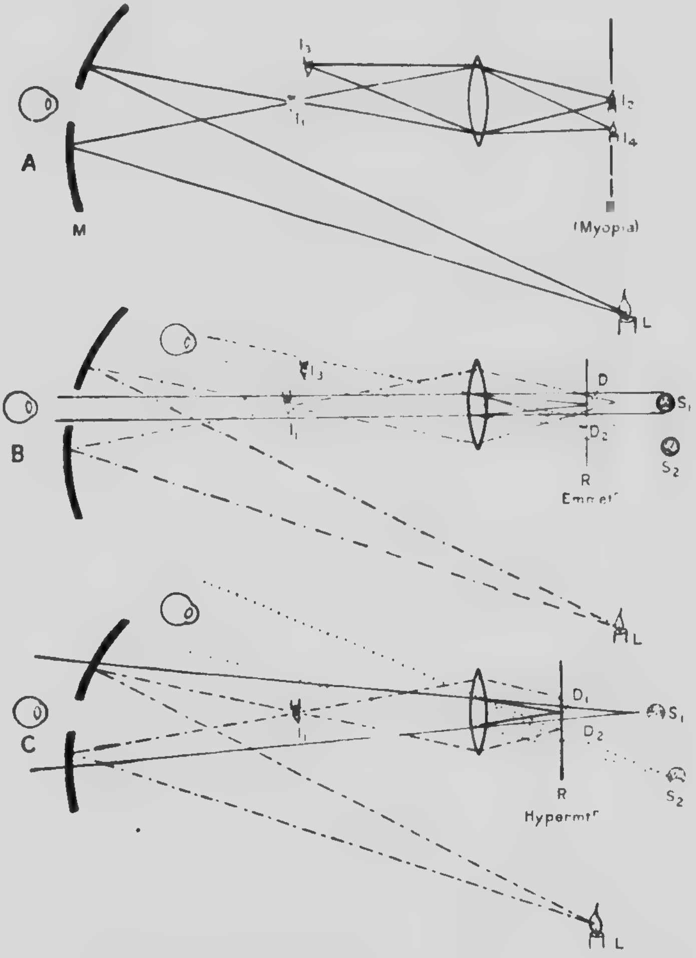


FIG. 36.—Retinoscopy with a concave mirror. A, myopic eye; B, emmetropic eye; C, hypertropic eye; R, retina.

appearing to the observer behind the observed eye as at S_1. If the mirror move so that I_1 moves to I_3, D_1 will move to D_2 and the image at infinity will appear to the observer to have moved to S_2, *i.e.* its motion will be against the mirror.

In hypermetropia the retina R is still closer to the lens and the circle of diffusion correspondingly larger and dimmer, as shown in Fig. 36 C. The rays from D_1 on leaving the eye will be divergent, and their focus will be behind the retina at S_1, forming a virtual image. If the mirror be moved as before, D_1 will move to D_2 and the image seen, S_1, will appear to move to S_2, *i.e.* also against the motion of the mirror. If the plane mirror be used, the retina will be illuminated by a virtual image of L situated as far behind the mirror as L is really in front of it. This virtual image always moves in the opposite direction to the mirror, but the paths of the emerging rays will still be the same relatively to the image of the source of light, *i.e.* as the motion of the illuminating point is reversed in every case, the movement of the shadow is also reversed, and in myopia will now be against the mirror, and with it in emmetropia and hypermetropia.

To ascertain the refraction; in myopia, place concave glasses in front of the subject's eye until the shadow which originally moved with the mirror is seen to move against it. The lowest concave glass which effects this is the correcting lens of the myopia.

If the shadow move against the mirror, the eye is emmetropic, hypermetropic, or slightly myopic.

If on using a convex lens + 0·5 D.[1] the shadow now move with the mirror, then the eye is slightly myopic, about – 0·5 D.

If it continue to move against the mirror with + 0·5 D., but move with it with + 1 D., the eye is emmetropic.

If the motion be still against the mirror, with a lens of + 1 D. the eye is hypermetropic, and stronger + lenses are used, until one is found which causes the motion of the shadow to go with the mirror. The measure of the hypermetropia is 1 D. less than the number of this glass, as it has evidently over-corrected the refraction.

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[1] The unit of refraction is taken as a convex lens of one metre focus, which is called the Dioptric Unit or Dioptry (D).

LESSON XXXVII

THE OPHTHALMOMETER—THE PERIMETER

The Ophthalmometer.—In the examination of Sanson's images (Lesson XXXIV, p. 118) the student will have observed that he obtains a bright erect image of any object reflected from the anterior surface of the cornea. For a given object, the apparent size of this image is dependent on the radius of curvature of this surface. If, therefore, there were any method of measuring the size of the image (or of measuring the relative displacement of two images), it would be possible to calculate this radius.

Such a measurement is possible with the ophthalmometer. The instrument consists essentially of two luminous objects, or 'mires,' and of a telescope by which is observed the reflection of these mires from the surface of the cornea. The telescope has a double object glass, and a bi-prism placed between the two parts. This arrangement gives a double image of the eye of the subject, with the mires reflected from it, and the degree of separation of the images of the eye is so arranged that the double images of the mires overlap to an arranged amount. The degree of overlap measures the curvature of the surface.

The exact working directions will depend on the construction of the particular instrument used, which are variously described by their makers as ophthalmometers, or astigmometers.

The importance of the measurement of the curvature of the cornea lies in the fact, that it is usually the structure at fault, when the eye has the defect of astigmatism.

The Perimeter.—This instrument consists of a quadrant which can be revolved so as to trace out a hollow sphere. The subject places his chin on a rest, gazes at the centre of the sphere, and regards the little patches of white or coloured paper, that slide up and down the quadrant. To obtain the extent of the field of vision for, *e.g.* white, the patch of paper is placed outside the field, and gradually moved inwards till it just becomes visible. This spot is recorded on a card at the back of the apparatus, the quadrant revolved, and another reading taken. The whole field can thereby be mapped out.

The student should determine his field for colours as well as for white light, and mark out the area of the blind spot.

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PRINTED BY
SPOTTISWOODE AND CO. LTD., LONDON
COLCHESTER AND ETON